DESCRIPTIVE TAXONOMY, BIOSTRATIGRAPHIC CORRELATION AND PALEOENVIRONMENTAL RECONSTRUCTION OF AN UPPER CARBONIFEROUS MACROFLORAL ASSEMBLAGE, BAY ST. GEORGE BASIN, SOUTHWESTERN NEWFOUNDLAND

ARDEN ROY BASHFORTH

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by

Arden Roy Bashforth

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Abstract

A diverse, well preserved macrofloral assemblage (herein termed the Blanche Brook Assemblage), which is characterized by large tree petrifactions of cordaitean affinity and an array of adpressed foliage that includes lycopsids, sphenopsids, ferns, pteridosperms and cordaiteans, has been recovered from coal-bearing strata of the Upper Carboniferous Barachois Group of the Bay St. George Basin, southwestern Newfoundland. The locality constitutes part of the northernmost onshore extent of the Maritimes Basin of eastern Canada, which developed on the southern margin of paleoequatorial Laurentia and is included in the Europe Paleoarea of the Euramerian Paleokingdom. Although the fossil site was initially investigated in the late 1800's, the present study comprises the first comprehensive taxonomic description and biostratigraphic correlation of the macrofloral assemblage, and provides an interpretation of the depositional environment and paleoecological conditions under which the flora flourished.

Recovery of very well preserved cuticles exhibiting fine epidermal cellular details from adpressed cordaitean and pteridosperm foliage reflects the fact that fossiliferous strata have experienced very little deformation or burial metamorphism, and supports earlier claims that rocks in the northern part of the Bay St. George Basin and on Port au Port Peninsula are thermally immature. Paleoecological evidence and homotaxial biostratigraphic comparison of selected adpressed macroflora with other localities in the Europe Paleoarea (e.g., Maritimes Basin, western and central Europe, midcontinental

North America) indicates that the assemblage is middle to late Bolsovian in age, which corroborates ages determined earlier from palynological studies.

Fossiliferous and associated rocks in the stratigraphic succession are here subdivided and assigned to one of seven sublithofacies, each of which represents a distinct depositional environment characterized by its sedimentology and stratigraphy, vertical and lateral relationships with other sublithofacies, and plant fossil assemblages. The strata appear to record sediment accumulation in a coarse grained meandering stream system that occupied a narrow alluvial plain and was characterized by poorly developed levee/backlevees that were consequently overtopped or breached during frequent flood events. The distribution and relative abundances of taxa within each sublithofacies, including miospores recorded from associated coal seams, have been integrated with previously interpreted habitat preferences known for flora represented at the fossil site. This has resulted in construction of a working paleoenvironmental model for the Blanche Brook Assemblage, which indicates that there was considerable habitat partitioning and even competition for ecological niches between members of the five main plant groups in response to ecological preferences of each taxa. In particular, there is evidence for interspecific habitat partitioning within the medullosan pteridosperms occupying the floodplains and levee/backlevees, while competition may also may existed between certain medullosan pteridosperms and sigillarian arborescent lycopsids for drier edaphic substrates in these habitats. Likewise, clastic swamps were inhabited by an array of flora, the composition of which depended on the rate of peat versus clastic sediment accumulation that resulted from frequent incursions of sediment-laden floodwaters.

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Chapter 1 – Introduction

Coal-bearing strata along "Rivière Blanche" just north of Stephenville, Newfoundland were initially investigated over 125 years ago by A. Murray and J.P. Howley of the Geological Survey of Newfoundland during a reconnaissance survey to determine the economic potential of coal seams recorded in Carboniferous strata of the area. Although they concluded, with dejection, that coal seams were of poor quality and limited thickness, they did remark on their discovery of a horizon of bluish clay above a coal seam "*...filled with most beautiful impressions of fossil ferns, in an admirable state of preservation*" (Howley 1917, p. 21). Additionally, they noted that associated sandstones contained abundant well preserved, prostrate trees complete with trunks, limbs and branches "*...so that, as seen from a little distance, the appearance of the ground reminds one of a windfall or drift of modern wood upon a beach of sand*" (Murray and Howley 1881, p. 327). They must have collected representative specimens of "wood" and "ferns" and submitted them to Sir. J.W. Dawson for identification, as shortly thereafter Dawson (1891; see p. 14, 15) published the first (and only) brief descriptive account of macroflora from Blanche Brook (present geographical name). Although Bell (1948) examined and figured macroflora and fauna from Lower Carboniferous strata of southwestern Newfoundland, plant fossils from Upper Carboniferous rocks along Blanche Brook were not included in his study.

The macrofloral assemblage described in this study (hereafter referred to as the Blanche Brook Assemblage – BBA) was recovered from these same rocks that Murray

and Howley first recorded in the late 1800's. In present lithostratigraphic terms, the fossiliferous beds represent the uppermost strata of the coal-bearing "undivided Barachois Group" of Knight (1983), and constitute the youngest rocks within the Bay St. George Basin of southwestern Newfoundland. This basin is part of the northernmost onshore extent of a larger network of basins, collectively termed the Maritimes Basin (Fig. 1.1), that extended over much of Atlantic Canada during the Upper Paleozoic. Like several other fossil localities within the Maritimes Basin, in particular the Sydney Basin of northern Nova Scotia (Fig. 1.1), the excellent quality of preservation of specimens studied herein results from their preservation in essentially undeformed and thermally immature sedimentary rocks.

Interestingly, the brief observations of Murray and Howley (1881), Howley (1917) and Dawson (1891) are the last published documentation of the BBA. Recent reinvestigations by the author revealed that, in addition to the aforementioned "bluish clay" unit of Howley (1917), diverse adpression assemblages can be found in at least four other mudstone or siltstone horizons. Throughout this century the fossil locality has apparently been visited by a variety of geologists, including university students and local amateurs; it is, therefore, somewhat surprising that no further work has been carried out to determine the diversity, preservational modes, and biostratigraphic and paleoecological implications of this well preserved and potentially significant macrofloral assemblage.

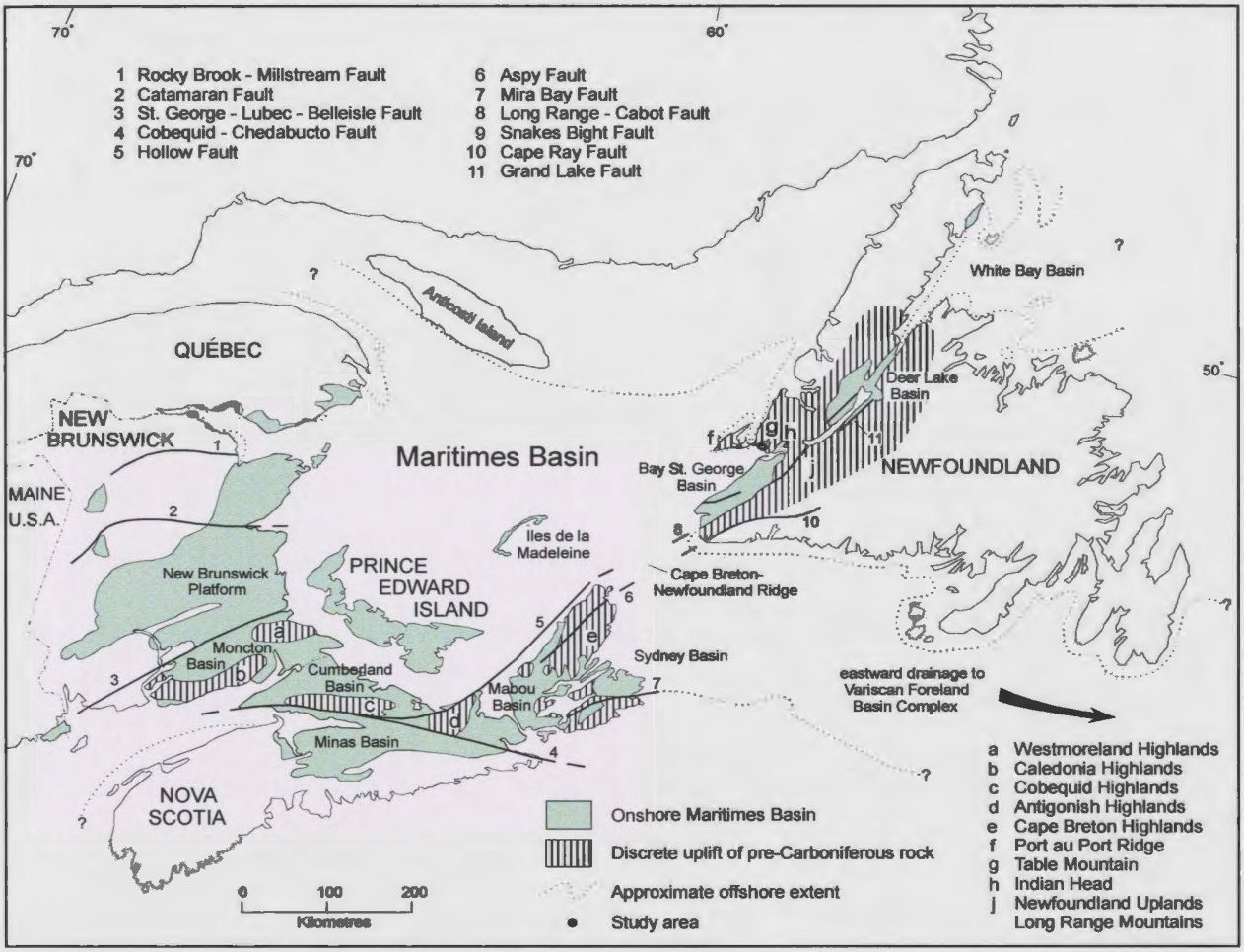


Figure 1.1. Maritimes Basin of eastern Canada, showing distribution of major faults, basins and adjacent highlands, and study area. Note position of the Cape Breton-Newfoundland Ridge and overall drainage direction. Data from Knight (1983), Sanford and Grant (1990), Gibling et al. (1992), Hyde (1995) and van de Poll et al. (1995).

1.1 Maritimes Basin (Regional Geological Setting)

The Late Devonian to Early Permian Maritimes Basin (Williams 1974) of eastern Canada (Fig. 1.1) is a large (ca. 148 000 km^2), composite successor basin (St. Peter 1993) that developed in a paleoequatorial position (Murthy 1985) on the southern margin of the paleocontinent of Laurentia (Fig. 1.2) (Scotese and McKerrow 1990). The basin constitutes a structurally complex network of northeast-trending grabens or intramontane basins separated by discrete ridges or topographic highs that often formed sediment sources (Fig. 1.1) (Belt 1968a, 1969). These basins and intervening arches developed as the combined result of post-orogenic subsidence (Howie and Barss 1975a, b) after the Salinic and Acadian orogenies, followed by dextral strike slip faulting associated with collision between Laurentia and the northern margin of Gondwana (Fig. 1.2.; Poole 1967; Webb 1969; Bradley 1982; Langdon and Hall 1994). It is apparent from considerable evidence [e.g., basement structure contouring (Wade et al. 1975); geophysical surveys (Watts 1972; Haworth 1975; Langdon and Hall 1994); and lithostratigraphy (Howie and Barss 1975a, b)] that one such arch of uplifted pre-Carboniferous basement rock extended across Cabot Strait between southwestern Newfoundland and northern Nova Scotia. This major topographic high, termed the Cape Breton-Newfoundland Ridge (Fig. 1.1; Watts 1972), evidently separated the Maritimes Basin throughout much of its development into the Sydney Basin on the east and a larger depocentre, variously termed the "Fundy Basin" (Belt 1965, 1968a, b), "Fundy Epieugeosyncline" (Hacquebard 1972; Howie and Barss 1975a, b) or "St. Lawrence Basin" (Geldsetzer 1979), on the west.

Paleobotanical or paleophytogeographical evidence indicates that the Maritimes

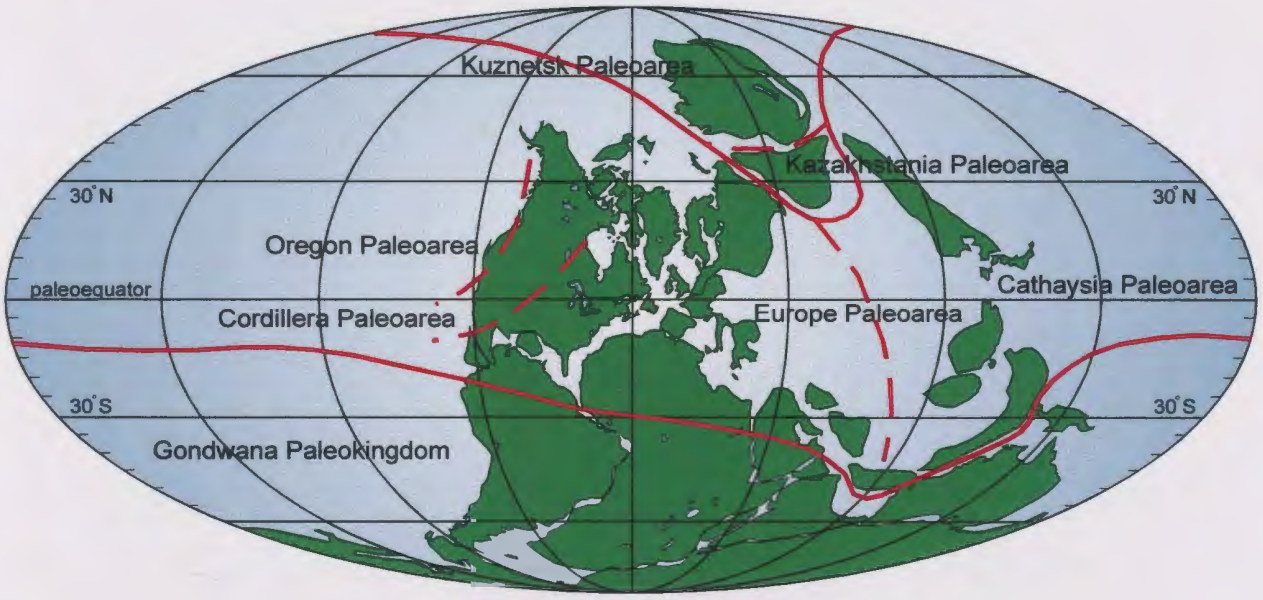


Figure 1.2 Global reconstruction demonstrating the distribution of Upper Carboniferous paleophytogeographical units (phytochoria). Paleokingdoms separated by solid lines, and comprise paleoareas separated by dashed lines. Euramerica Paleokingdom comprises Oregon, Cordillera, Europe and Cathaysia paleoareas; Angara Paleokingdom contains Kuznetsk and Kazakhstania paleoareas. Base map adapted from Scotese and McKerrow (1990); distribution of phytochoria from Cleal and Thomas (1991).

Basin is part of the Europe Paleoarea of the paleoequatorial Euramerian Paleokingdom (Fig. 1.2) (Chaloner and Meyen 1973; Cleal and Thomas 1991). More precisely, Pfefferkorn and Gillespie (1980) indicated that the basin was part of the "Acadian Floral Province", which was separated from the "Interior-Appalachian Floral Province" of midcontinental North America by the northern Appalachian Mountains during the Upper Paleozoic.

Studies verify that an enormous quantity (perhaps 12 to 16 km) of now partially exhumed strata accumulated in the Maritimes Basin between the Late Devonian and Early Permian (Sanford and Grant 1990; Ravenhurst et al. 1990; Ryan and Zentilli 1993; Grist et al. 1995). This implies that a thick blanket of sediment once covered much (if not all) of Atlantic Canada plus adjacent parts of U.S.A. and western and central Europe (Ryan et al. 1991a; Ryan and Zentilli 1993). Regional scale paleoflow data suggest a predominantly northeast directed movement of sediment, and imply that the central and northern Appalachians of the eastern United States were a major drainage source during the Late Carboniferous and Early Permian (van de Poll 1973; Gibling et al. 1992). After traversing the network of subbasins within the composite Maritimes Basin, drainage likely continued eastward (Gibling et al. 1992) to debouch into the Variscan Foreland Basin Complex of western Europe (Fig. 1.1) (Cleal 1997).

Subdivision of the thick sedimentary package of the Maritimes Basin was first attempted by Bell (1929, 1938, 1944), who recognized six distinct and regionally correlative stratigraphic units based primarily on macropaleontological evidence. Further work involving palynological and lithofacies distributions (e.g., Hacquebard 1972; Howie

and Barss 1975a, b) have resulted in important emendations; of particular significance are the recent lithostratigraphic revisions proposed by Ryan et al. (1991b). Figure 1.3 demonstrates correlation between lithostratigraphic units of mainland Canada and those of the Bay St. George Basin, and provides a brief summary of the lithologies and paleoenvironmental setting of deposition for each unit.

As defined by van de Poll et al. (1995), and as applied in this manuscript, the "Maritimes Basin" represents the onshore and offshore, and structural and erosional remnants of a once much more extensive cover sequence of Upper Paleozoic rocks in the Appalachian region of Atlantic Canada.

1.2 Bay St. George Basin

1.2.1 Geological and Tectonic Setting

The Bay St. George Basin of southwestern Newfoundland (Fig. 1.4A) forms part of the northernmost onshore extent of the Maritimes Basin, and constitutes a northeast-trending, fault-bounded, pull apart basin that resulted from wrenching and dextral strike slip movements adjacent to the Long Range Fault (Bradley 1982; Knight 1983; Hyde et al. 1988). Elevated regions surrounding the basin, such as the Port au Port Ridge and Newfoundland Uplands (Fig. 1.1), contributed up to 10 000 m of predominantly terrigenous detritus to the depocentre between the Late Devonian(?) and Late Carboniferous (Baird and Coté 1964; Knight 1983), and likely separated the Bay St. George Basin from the contemporaneous Deer Lake Basin to the northeast (Knight 1983; Hyde 1995).

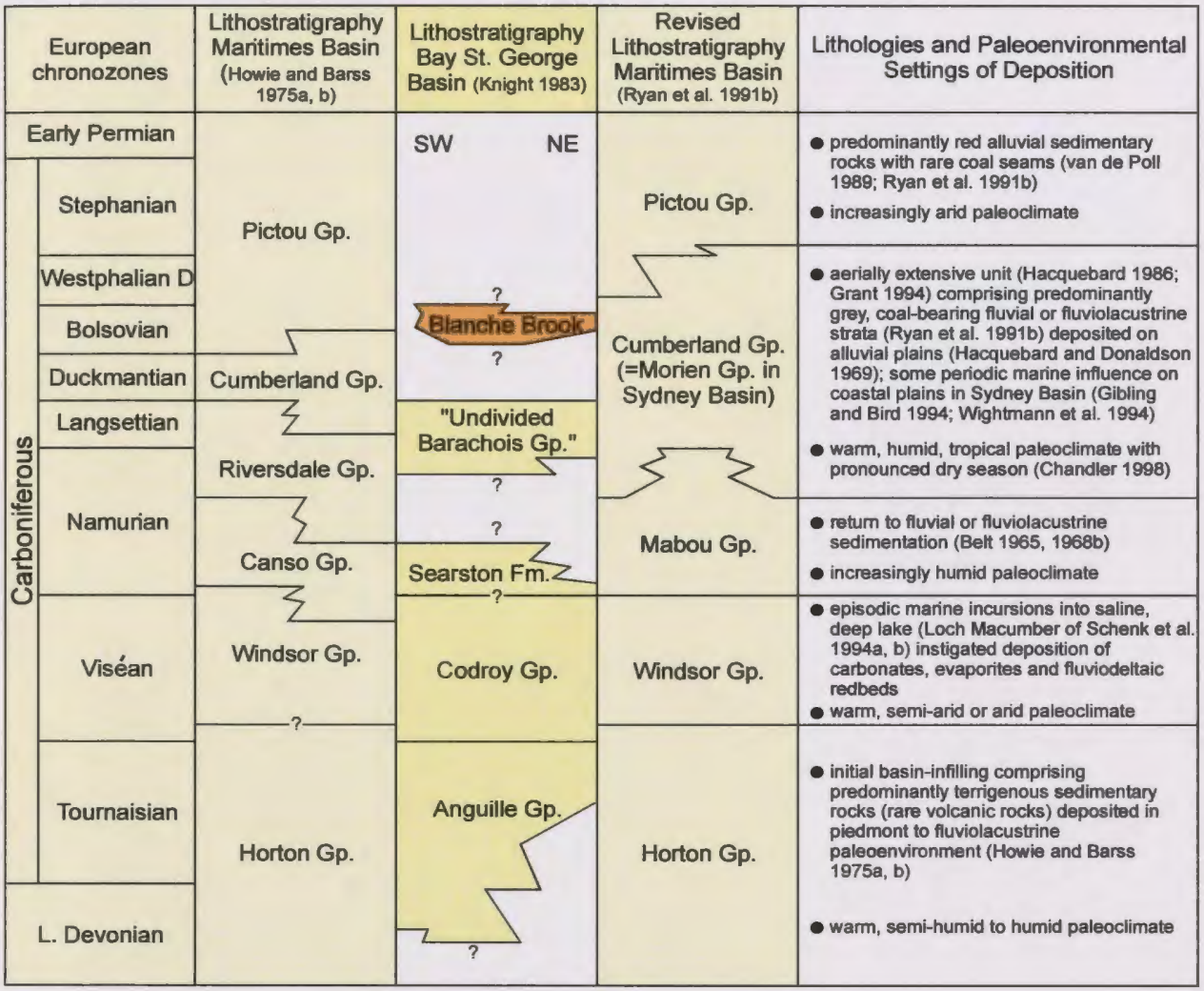


Figure 1.3. Generalized stratigraphy for Maritimes Basin of eastern Canada (including interpretation of paleoenvironmental setting during deposition of each lithostratigraphic unit) and correlation with strata of Bay St. George Basin, southwestern Newfoundland. Chart modified from Hyde (1995), with additional data from Gibling (1995) (other authors quoted within figure.)

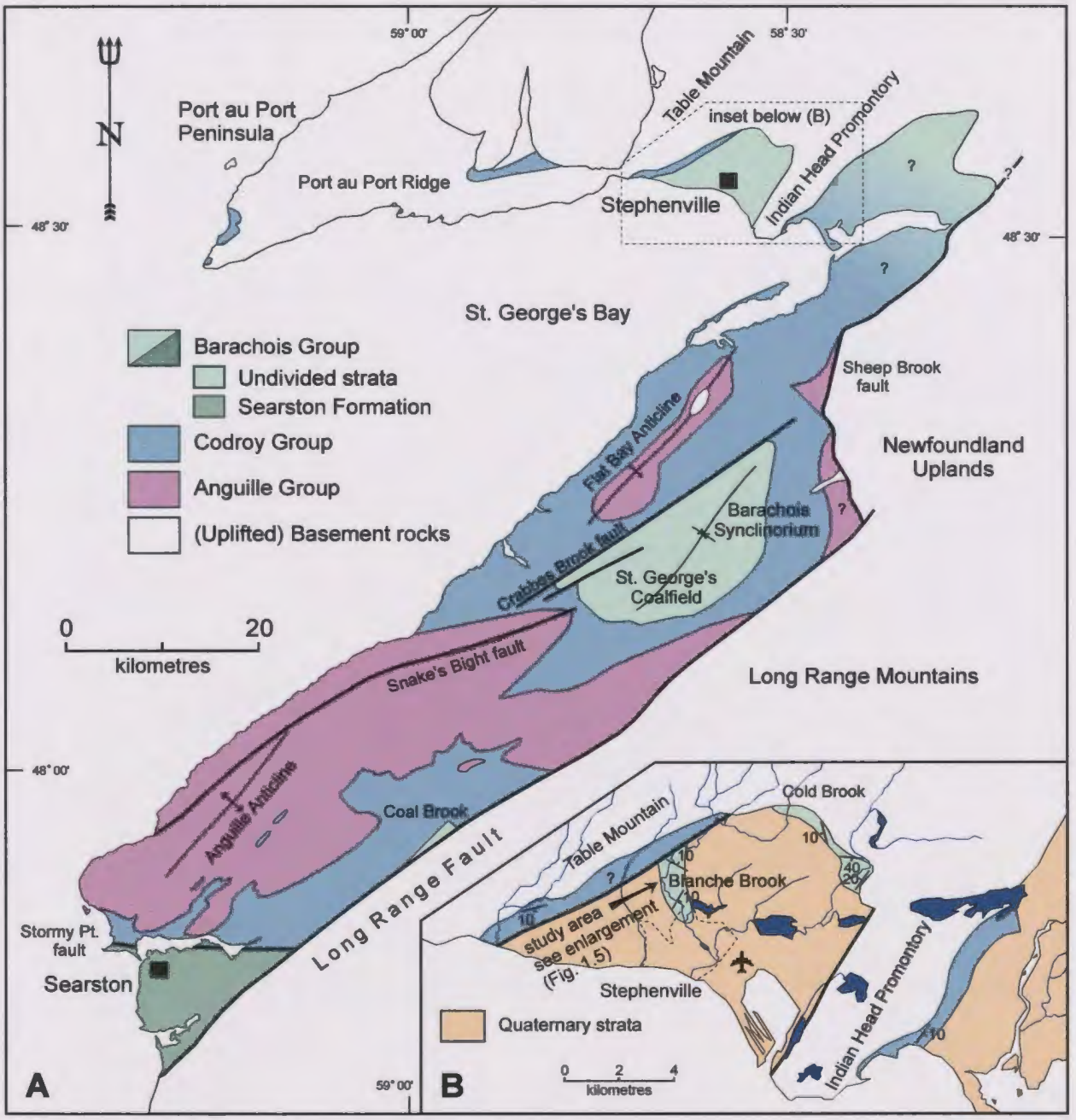


Figure 1. 4. A. Geology of the Bay St. George Basin, southwestern Newfoundland, showing distribution of lithostratigraphic units, major structural features and uplifted basement rocks. After Knight (1983). B. Geology of study area - a small subbasin bounded by Table Mountain and Indian Head Promontory. Note that exposure is limited in northern parts of Bay St. George Basin due to thick cover of Quaternary glacial deposits. Geology represents compilation of Riley (1962), Knight (1983), Williams (1985) and Williams and Cawood (1989).

Geophysical data (e.g., Peavy 1985; Kilfoil 1988; Miller et al. 1990; Langdon and Hall 1994) and the presence of isolated outcrops rimming Port au Port Peninsula [Fig. 1.4A; see Williams et al. (1996) and references therein] indicate that much of St. George's Bay is underlain by Carboniferous strata, implying that the Bay St. George Basin was once considerably more extensive. Although the Bay St. George Basin probably was separated from Sydney Basin by the Cape Breton-Newfoundland Ridge (Fig. 1.1) during much of its evolution, lithostratigraphic (Howie and Barss 1975a, b) and paleobotanical evidence (Bashforth 1997; Bashforth et al. 1997) indicates that these contemporaneous basins were likely in sedimentary connection during the Late Westphalian.

1.2.2 Stratigraphy

The Barachois Group records the final phase of basin infilling in the Bay St. George Basin, and overlies older strata of the Anguille Group (Late Devonian(?) to Tournaisian fluviolacustrine rocks) and Codroy Group (Viséan saline "lacustrine" to fluviodeltaic redbeds) (Figs. 1.3, 1.4A; Knight 1983). The Barachois Group can be informally subdivided into three sedimentary successions that are spatially and (at least in part) temporally distinct (Figs. 1.3, 1.4A) – in ascending order they are the Searston Formation, "undivided Barachois Group" of St. George's Coalfield, and "undivided Barachois Group" at Blanche Brook (study area).

The Searston Formation (Bell 1948; Knight 1983) constitutes an approximately 2 500 m thick section of meandering stream deposits that are likely equivalent to the Mabou Group of Nova Scotia (*sensu* Ryan et al. 1991b) (Fig. 1.3). Bell (1948) inferred a

Namurian A age for the formation based on the presence of *Lepidodendron volkmanniamm* Sternberg, *Diplotmema adiantoides* (Schlotheim) and *Adiantites temuifolius* (Göppert); this age was corroborated by recovery of Namurian A miospore assemblages from the formation by Utting (1965, 1987, *in* Knight 1983).

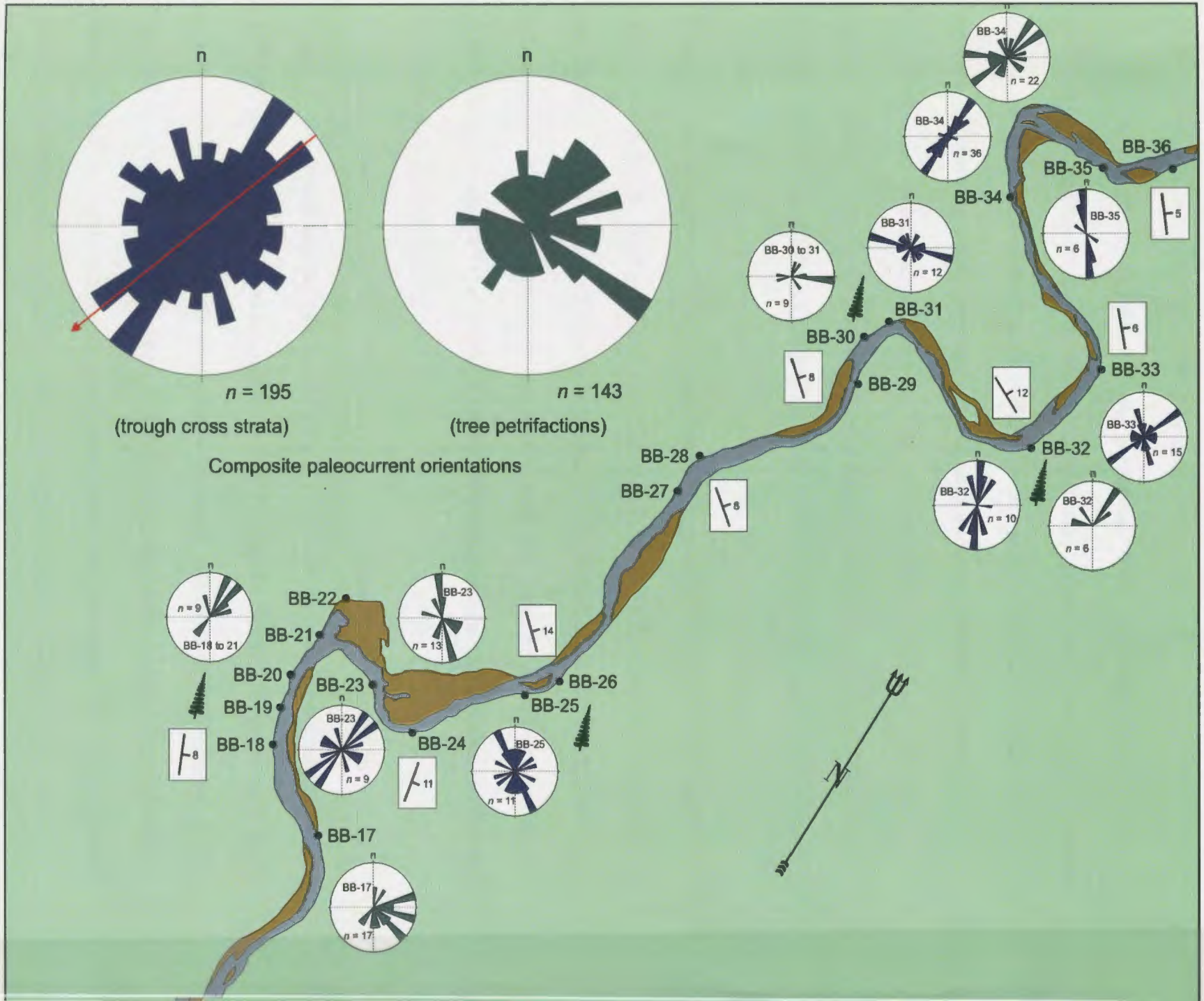
The St. George's Coalfield (Fig. 1.4A) is a doubly plunging syncline that contains approximately 1 200 to 1 600 m (Hayes and Johnson 1938; Peavy 1985; Solomon and Hyde 1985) of coal-bearing, fluviolacustrine strata of the "undivided Barachois Group" of Knight (1983). According to Hyde (1995), the entire stratigraphic succession is a fining upward megasequence comprising a lower "coarse" and an upper "fine" unit (Fong 1976; Solomon 1986). Bell (*in* Hayes and Johnson 1938) suggested that the rocks were Langsettian in age based on the presence of *Sphenopteris hoeninghausi* Brongniart. Recovery of Langsettian miospore assemblages from the same strata (Hacquebard et al. 1961; Solomon 1986; Hyde et al. 1991) supports this conclusion, and suggests correlation with the Lower Cumberland Group (Fig. 1.3) (*sensu* Ryan et al. 1991b). However, both macrofloral (Bell 1948, 1960) and palynological (Solomon 1986) evidence reveals that basal portions of the "undivided Barachois Group" may in fact be Namurian in age, thus forming a chronostratigraphic continuum with the underlying Searston Formation (Solomon 1986).

Based on maceral, geochemical and spore composition data from coal seams within St. George's Coalfield, Hyde et al. (1991) inferred that most of the peats in wet, forested tracts occupying lowlying interfluves subject to sediment influxes.

1.3 "Undivided Barachois Group" at Blanche Brook (Study Area)

1.3.1 Local Geological Setting

The uppermost rocks of Knight's (1983) "undivided Barachois Group", which constitute the study section, comprise an approximately 165 metre thick section of subhorizontal, gently warped and thermally immature fluvial sedimentary rocks exposed in the northernmost part of the Bay St. George Basin near the town of Stephenville, located on the north shore of St. George's Bay (Figs. 1.3, 1.4B, 1.5). Despite the fact that much of the area is covered by a thick blanket of Quaternary glacial deposits (Brookes 1974; Grant 1991), small, scattered outcrops of essentially undeformed, plant fossil-bearing strata are exposed on the banks and within the stream bed of Blanche Brook (Fig. 1.5). The area of outcropping extends from within Stephenville (UTM 83757875, Map Sheet 12 B/10) to approximately 4700m (measured along stream bed) north of town (UTM 831819). The rocks presumably accumulated in a small subbasin bounded by precursors of the Indian Head Promontory to the southeast and Table Mountain to the northwest (Fig. 1.4; Bashforth *in* Williams et al. 1996). The strata may onlap directly (with angular unconformity) on Precambrian or Lower Paleozoic rocks of the Humber Tectonostratigraphic Zone (Riley 1962; Williams 1985; Williams and Cawood 1989). Conversely, strata in some parts of the subbasin (e.g., near Cold Brook and upper reaches of Blanche Brook) may lie conformably(?) above a thin layer of Codroy and/or Anguille Group sedimentary rocks (see limestone conglomerate of Riley 1962, p. 35).


n
n = 195
(trough cross strata)
n
n = 143
(tree petrifactions)
Composite paleocurrent orientations
BB-34
n = 22
BB-34
n = 36
BB-36
BB-35
BB-34
BB-35
n = 6
5
BB-31
n = 12
BB-30 to 31
n = 9
BB-31
BB-30
6
8
BB-29
12
BB-33
BB-33
n = 15
BB-28
BB-32
BB-27
8
BB-32
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BB-22
BB-23
n = 13
n = 9
BB-18 to 21
14
BB-21
BB-20
BB-23
BB-26
BB-19
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n = 17
N

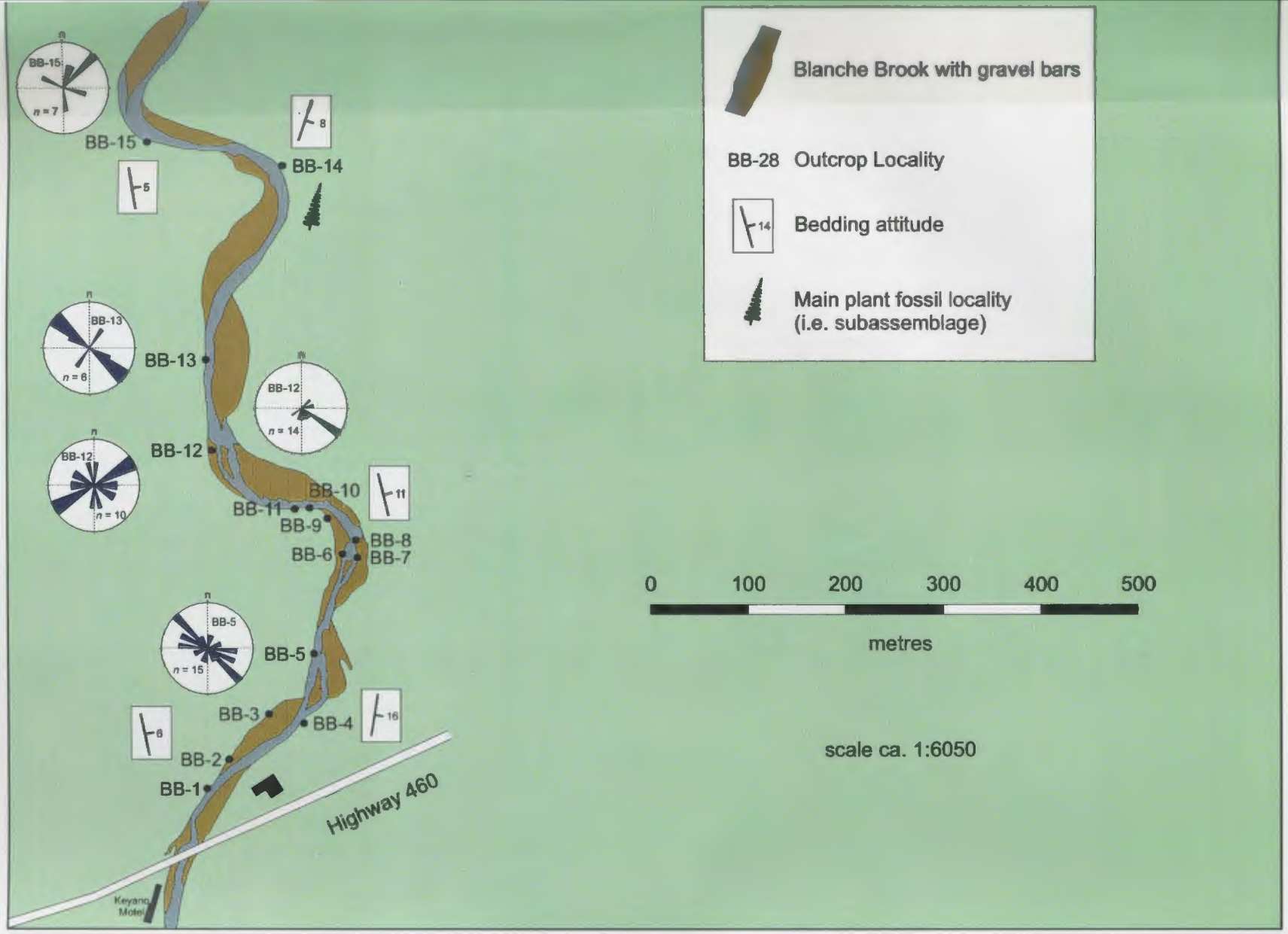

Figure 1.5. Schematic illustration of Blanche Brook, showing distribution of outcrop localities, bedding attitudes, main sites containing macroflora described herein, and paleocurrent orientations measured from trough cross strata and tree petrifactions. Red arrow on rose diagram showing composite paleocurrent orientations of trough cross strata signifies vector mean (232.2°) and postulated paleoflow direction (from northeast to southwest). See Fig. 1.4 for approximate area represented by this figure.

1.3.2 Previous Paleontological and Paleoenvironmental Studies

In addition to remarking on the well preserved "ferns" and prostrate tree petrifactions along Blanche Brook, Murray and Howley (1881) and Howley (1917) briefly documented the preservational mode of the large tree petrifactions, and noted the presence of *Stigmaria* underclays beneath thin, uneconomic coal seams (or poorly developed coaly, carbonaceous horizons). As previously mentioned, Dawson (1891) described numerous tree petrifactions and adpressed foliage specimens from undisclosed localities within the Barachois Group (Fig. 1.6). Unfortunately, although much of his material almost certainly was collected from Blanche Brook, some specimens, such as *Sphenopteris hoeninghausi* (Fig. 1.6, see also p. 11), presumably were collected from older strata of the St. George's Coalfield. Dawson (1891) concluded that petrifactions of both conifer and cordaitean affinity were present in his collection, and he described and figured several lycopsids (some specimens likely were not collected from Blanche Brook). In addition, Dawson (1891) provided a list of sphenopsids, ferns and pteridosperms that he identified in the collection (Fig. 1.6).

Hacquebard et al. (1961) collected miospores from strata at Blanche Brook, and considered the assemblage equivalent to Bell's (1938) *Linopteris obliqua* Biozone of the middle Pictou Group (=Morien Group) in Sydney Coalfield. Bell (1938) considered the *L. obliqua* Biozone to be Bolsovian in age (prior to formal definition of the Westphalian D), but it has since been redefined as Westphalian D in age based on evidence from microflora (Hacquebard et al. 1961) and macroflora (Zodrow and McCandlish 1978). During a study of the Codroy Group on Port au Port Peninsula, macrofloral specimens

Lycopsids:	*Lepidodendron murrayanum* sp. nov.; *Lepidophyllum triangulare*; *Lepidophyllum lanceolatum*; lycopsid leaves; *Stigmaria ficoides*
Sphenopsids:	*Calamites suckovii* (sic); *Calamites cistii*; *Calamites cannaeformis*(?)(sic); *Annularia sphenophylloides*; *Annularia longifolia*(?)
Ferns:	*Pecopteris abbreviata*; *Pecopteris oreopteroides*; *P. arborescens* (fertile); *Sphenopteris* (*Cheilanthites*) *hoeninghausi***; *Sphenopteris* sp.; *Psaronius* sp.
Pteridosperms:	*Neuropteris rarinervis*; *Neuropteris auriculata*; *Alethopteris lonchitica*; *Dictyopteris* sp.
Other Gymnosperms:	*Cordaites borassifolia*; petrifactions identified as *Dadoxylon materianum* (from *Walchia*) and *Cordaioxylon* sp. (from *Cordaites*)

Figure 1.6. List of macroflora collected by A. Murray and J.P. Howley from Upper Carboniferous rocks in the Bay St. George Basin and submitted to Sir J.W. Dawson (1891) for identification. Many of the specimens likely were recovered from strata along Blanche Brook, although some (**) presumably were collected from older rocks.

were collected from Blanche Brook by Dix (1982), who suggested the strata were Bolsovian (middle Pennsylvanian) in age (Forbes *in* Dix 1982, p. 122). More recently, a palynomorph assemblage collected by Hyde et al. (1991) corroborated this Bolsovian age.

Solomon and Hyde (1985) briefly described two coal seams (localities BB-29 and BB-30 of present study, Fig. 1.5) from Blanche Brook. They concluded that intrinsic conditions were unfavorable for the generation of thick peats; bogs either were drowned when shallow lakes developed (rising water table), or were buried and choked off by crevasse splay deposition shortly after inception. The maceral, geochemical and palynomorph compositions of these same two coal seams were analyzed in detail by Hyde et al. (1991). These authors suggested that peats were dominated by herbaceous vegetation, and developed in a very wet, relatively unwooded fen type environment characterized by frequent incursions of flood water. It is important to note that this

paleoenvironmental reconstruction was based primarily on differing proportions of coal macerals within each coal seam (e.g., tissue preservation and gelification indices), which have been used by some workers to assess and interpret depositional environments (e.g., Diessel 1982, 1986; Harvey and Dillon 1985; Kalkreuth et al. 1991). Regardless, DiMichele and Phillips (1994) have strongly cautioned against using coal petrography and maceral ratio indices alone to deduce hydrologic conditions and parent vegetation of coals.

Based on the sedimentology and spatial distribution of lithofacies in the fossiliferous section, Bashforth (*in* Williams et al. 1996) suggested the strata accumulated in a meandering stream depositional environment. Preliminary identification of the adpression assemblage was given by Bashforth (1997) and Bashforth et al. (1997), who suggested the BBA was late Bolsovian or early Westphalian D in age based on paleoecological evidence and homotaxial biostratigraphic correlation with other localities within the Europe Paleoarea of the Euramerian Paleokingdom (Fig. 1.2). Based on homotaxial correlation of the BBA with macroflora of the Morien Group in the Sydney Basin and the Mabou Mines Section (Inverness Formation) in the Mabou Basin (Fig. 1.1), Bashforth (1997) and Bashforth et al. (1997) argued that a thin veneer of sediment was deposited over the Cape Breton-Newfoundland Ridge during the Late Westphalian.

1.3.3 Thermal Maturity

Upper Carboniferous strata in the northern part of the Bay St. George Basin have very low thermal maturities based on vitrinite reflectance, clay mineral assemblages and

illite crystallinity measurements (Hyde et al. 1985, 1991). Similarly, the Codroy Group (Hyde et al. 1985; Utting 1987) and underlying Lower Paleozoic basement rocks (Nowlan and Barnes 1987; Williams et al. *in press*) on the Port au Port Peninsula also have low thermal maturities.

Coal seams from along Blanche Brook have vitrinite reflectance measurements between 0.45 and 0.56% (mean $R_{0\ max}$; Hacquebard and Donaldson 1970; Hyde et al. 1991), implying coal ranks of subbituminous B to high volatile bituminous C based on the geochemical stages of coalification proposed by Teichmüller and Teichmüller (1982). These low vitrinite reflectance data indicate that the strata have only been heated to temperatures at or near the oil window (Staplin 1982). Given the lack of deformation of the fossiliferous strata, it can be inferred that rocks of the study area have been buried only slightly since accumulation in the Bolsovian – this lack of burial metamorphism accounts for the excellent quality of preservation evident in macrofloral specimens collected from Blanche Brook.

1.4 Aims of Present Study

Despite the admirable state of preservation and potential significance of the macrofloral assemblage from Blanche Brook, studies at the site (except those of the previous century) have concentrated on the lithostratigraphy of the strata; age determinations based on miospore assemblages; and rank, distribution and paleoenvironmental inferences from associated coal seams. Consequently, the present thesis offers the first comprehensive taxonomic description and biostratigraphic correlation

of both the adpression and tree petrifaction assemblages, and provides an interpretation of the depositional environment and paleoecological conditions under which the flora once flourished. More specifically, the aims of this study are:

- To document each taxon recovered, and where possible, to refer specimens to previously established genera or species.
- To examine the mode and quality of preservation of the macroflora (especially the adpression assemblage) in order to assess the potential for future cuticular investigations at the site, and to substantiate earlier claims of low thermal maturity in the area.
- To determine the age of the site through biostratigraphic correlation (i.e., homotaxial comparison) of significant taxa with macroflora from better established localities within the Maritimes Basin and Europe Paleoarea, and to compare the age with those previously determined using miospores.
- To describe the sedimentology, stratigraphy, and lithofacies distribution of fossiliferous and associated sedimentary rocks in order to infer the depositional environment within which the macroflora lived.
- To construct a working paleoenvironmental model for the Blanche Brook Assemblage, which involves documentation of the relative abundance of various taxa within each depositional setting, and homotaxial comparison with previously published interpretations of the paleoecological preferences of taxa represented at Blanche Brook.

Chapter 2 – Study Methods

2.1 Fieldwork

Macrofloral specimens described in the present study were collected from outcrops along Blanche Brook over a period of ca. 2.5 weeks during the summers of 1994, 1996 and 1997. Concurrent with exploration for and recovery of plant fossils, the lithology, sedimentology, orientation and vertical distribution of fossiliferous and associated strata at 36 outcrops (Fig. 1.5) were measured and described in detail. Bedding attitudes were measured only from fine grained units with essentially parallel and originally horizontal bounding surfaces (i.e., those which accumulated by vertical accretion); dip angles range between 04 and 25° (ave. 10°, $n = 37$). Paleocurrent orientations were measured parallel to the long axis of individual troughs within trough cross-stratified sandstones and conglomerates, while down dip lineations (trend and plunge) were measured from numerous large tree petrifactions enclosed within these same coarse grained strata (Fig. 1.5). Computer generated rose diagrams were produced using the Thompson & Thompson Rose 1.0 software program.

While in the field, an attempt was made at lateral and vertical correlation of strata in adjacent outcrops in order to establish the vertical thickness of the entire stratigraphic succession. Unfortunately, the lack of continuous outcrop, subhorizontal attitude of the beds, and laterally heterogeneity of contemporaneous strata (i.e., sublithofacies, see below) strongly hampered such efforts at correlation.

2.2 Definition of Lithofacies, Sublithofacies, Blanche Brook Assemblage and Subassemblages

As used in the present study, the concept of a "lithofacies" encompasses a distinct package of sedimentary rocks that can be distinguished by its lithology, sedimentology, and vertical and lateral relationship with other lithofacies. During the course of investigation, rocks comprising the stratigraphic succession at Blanche Brook were determined to belong to either a "coarse (channel) lithofacies" or "fine (overbank) lithofacies". In order to better determine the paleoenvironmental setting within which the BBA flourished, these lithofacies were further refined and separated into distinct "sublithofacies", each of which constitutes a vertically and laterally restricted sequence of rocks deposited under specific environmental conditions (e.g., point bar, floodplain).

The vast majority of macrofloral specimens described in this study were recovered from grey to greenish grey mudstones or siltstones from five outcrops along Blanche Brook (Fig. 1.5). In the present study, the unique macrofloral assemblage recovered from each of these important outcrops is herein referred to as a "subassemblage". In contrast, some localities (e.g., BB-29, BB-34c) yielded only single specimens or very low diversity plant assemblages. Taken together, the Blanche Brook Assemblage (BBA) can be defined as the combination of these five macrofloral subassemblages, the tree petrifactions found in channel deposits, and any other macrofloral remains recovered during collection from localities along Blanche Brook.

2.3 Preparation and Analysis of Adpressions

Each fossiliferous slab was appropriately catalogued and labeled. An example of the labeling system is: BB-96-30-177, which translates as "slab 177 collected from Blanche Brook in 1996 from locality 30". Note that for the sake of simplicity, and because all specimens described in this study were collected from Blanche Brook, the same slab will hereafter be referred to as 30-177.

All specimens on all slabs were examined with a Zeiss low magnification binocular reflected light microscope using a Volpi Intralux 5000 fiber optic light source. Many slabs and contained fossils were covered with and obscured by heavy limonite staining (rust), which likely resulted from oxidation of pyrite nodules. It was discovered that much of this limonite could be removed by dousing affected parts of the slab with concentrated Schulze's Reagent (Appendix 1) for up to 30 to 45 minutes. When part of an adpression was still embedded within the slab matrix, the specimen was degauged using stainless steel dental tools with picks of various shapes. Certain specimens, particularly those with well preserved venations, or adpressions preserved on a dark colored background (i.e., those which were difficult to photograph), were traced using a *camera lucida* setup attached to the binocular microscope. The fine details of venation were much enhanced on certain decarbonized neuropteroid adpressions (i.e., impressions) by making latex peels of them with Lewiscraft rubbertex compound darkened with black, waterproof, fast drying India ink. These latex peels were far more informative than the original adpressions, as they were easier to observe, trace and photograph.

Well preserved devolatilized adpressions of several taxa were prepared (in part by E.L. Zodrow of University College of Cape Breton, Nova Scotia; Appendix 1) to determine whether or not cuticular material was retained within the coalified phytolemmas. Fortunately, very well preserved cuticles were procured from foliage of several different pteridosperms. Details of epidermal cell impressions on prepared cuticles were examined both with a Zeiss Photomicroscope III, and with a Hitachi S570 Scanning Electron Microscope (SEM) at an accelerating voltage of 20 kV.

2.4 Preparation and Analysis of Tree Petrifactions

Several tree petrifaction samples were thin sectioned in the transverse plane (i.e., perpendicular to long axis of tree) before examination and identification with a Zeiss Photomicroscope III under cross-nicols and plane polarized light. Furthermore, a single puck-shaped hand sample was cut (slabbed in transverse plane) and polished in order to ascertain the process(es) and preservational modes of the petrifactions. Two procedures were used to identify the agent responsible for permineralization of the petrifactions:

- two uncovered thin sections (i.e., without coverslips) were stained for carbonate composition using the Alizarin red S and potassium ferricyanide procedure (Appendix 2) recommended by Dickson (1965, 1966). Unfortunately, this method proved ineffectual for determination of the permineralizing mineral(s), although it is not certain why;
- a tiny sample (< 0.5 g) was shaved from a petrifaction and prepared for analysis (Appendix 3) by X-ray diffraction (XRD) at 100mA and 40 k, using CuKα radiation, and a scan from 5° to 70°2θ.

2.5 Preparation and Analysis of Spores

Megaspores, which were found in abundance as small, flattened circular bodies adhering to fossiliferous slabs from locality BB-32, were easily but carefully detached from the slabs with stainless steel dental picks and added to a vial filled with distilled water containing three drops of 1% phenol. Megaspores were briefly added to hydrofluoric acid (HF) to remove any clinging matrix material before treatment with concentrated Schulze's Reagent to macerate the specimens until clean of coalified material. Samples were initially examined with a Zeiss binocular reflected light microscope, and were subsequently analyzed and secondary electron images attained using a Hitachi S570 SEM. Megaspores were tentatively identified by the author before sending specimens to J.-P. Laveine at Université des Sciences et Technologies de Lille, Lille, France for confirmation of identification.

Detailed examination of slab 30-17 revealed that well preserved sporangia (comprising four sori arranged in an *Asterotheca*-type fructification) were preserved on the abaxial pinnule surfaces of a fertile specimen tentatively identified as *Lobatopteris* sp. A. Three sori were carefully teased from the pinnules before being macerated in a glass petri dish with concentrated Schulze's Reagent for ca. 1.5 to 2 hours. Although maceration removed much of the coalified matter from the sori, segregation and isolation of the contained miospores was accomplished only by mechanical breaking up of the fructification with a dental pick. Disintegrated organic remains were pipetted off and added to a small test tube filled with distilled water. The test tube was added to a Damon/IEC clinical centrifuge and spun on high in four intervals of 2 minutes each; the

test tube was decanted and filled with distilled water between each interval in order to rinse the sample of Schulze's Reagent. A drop of 1% polyvinyl, a water soluble fixer, was smeared with a toothpick onto a glass coverslip. Then the palynomorph/water mixture was pipetted from the test tube and smeared into the polyvinyl before heating the coverslip at ca. 48 °C in a Fisher slide warmer to evaporate all remaining water (ca. 15 to 20 minutes.) Under a fume hood, a single drop of elvacite glue was added to a glass microscope slide before the dried coverslip was carefully laid down; the elvacite glue was allowed to dry and harden overnight in a fume hood.

Prepared slides were examined and palynomorphs investigated at high magnification with a Zeiss Photomicroscope III. Although preliminary descriptions and tentative identifications were attempted, slides were afterward sent to J.-P. Laveine in France, an expert in examination of pecopterid miospores isolated from sporangia (e.g., Laveine 1969, 1970), for more confident taxonomic assignment.

2.6 Photography

The vast majority of macrofossils were photographed dry under high intensity yellow illumination using either an Olympus OM2 camera fitted with a macro lens. It was found necessary to immerse some fossils under a solution of water and 95% ethanol before photographing – this helped to enhance fine morphological features such as venation or hairs without the problem of reflection. Very small specimens and cuticles prepared on slides were photographed with a Wild Photomicroscope M400 using low angle fiber optic lights. High magnification photographs of cuticles, thin sections of tree

petrifactions, and spores isolated from *Lobatopteris* sp. A fructifications were taken with a Zeiss Photomicroscope III.

All photographs of both macro- and microfossils were taken using Kodak TMX 100 black and white print film; an exception were SEM images produced using Polaroid 665 Professional Positive/Negative Instant Pack film. Developing and printing was done by the author in the darkroom facilities of the Department of Earth Sciences at Memorial University of Newfoundland, and involved the use of a Durst Laborator 1200 Enlarger, Kodak TMX Developer, Kodak Rapid Fixer, and Kodak and Agfa glossy variable contrast black and white photopaper.

Chapter 3 - Modes of Preservation

Bateman (1991) introduced a novel scheme for classifying plant fossils based on their mode of preservation which combines aspects of progressive compositional change (organic components remaining) versus change in shape (degree of compression). This classification, which is used in the present thesis and summarized in Figure 3.1, is especially useful because it eliminates confusion between the process and product of fossilization (Bateman 1991).

3.1 Adpressions

The vast majority of adpressed macroflora examined, particularly those recovered from greyish mudstones and siltstones of the fine (overbank) lithofacies, can be classified as devolatilized or decarbonized adpressions (i.e., compressions or impressions, respectively; Fig. 3.1). Some fossils, such as axes referable to *Stigmaria* spp., *Calamites* spp. or *Myeloxylon* spp., are (at least partially) preserved as decarbonized petrifactions (Fig. 3.1). At some localities (especially BB-14 and BB-25), adpressions are distinctly yellowish brown and plastic, and are best referred to as "naturally macerated" volatilized adpressions (Fig. 3.1). These fossils are frequently (but not invariably) associated with either disseminated pyrite or a thin coating of very fine grained pyrite. Such an association seems to indicate that oxidation and devolatilization of organic components during the initial stages of coalification were largely inhibited because fossilization took place under markedly anoxic and reducing diagenetic conditions. Preferential

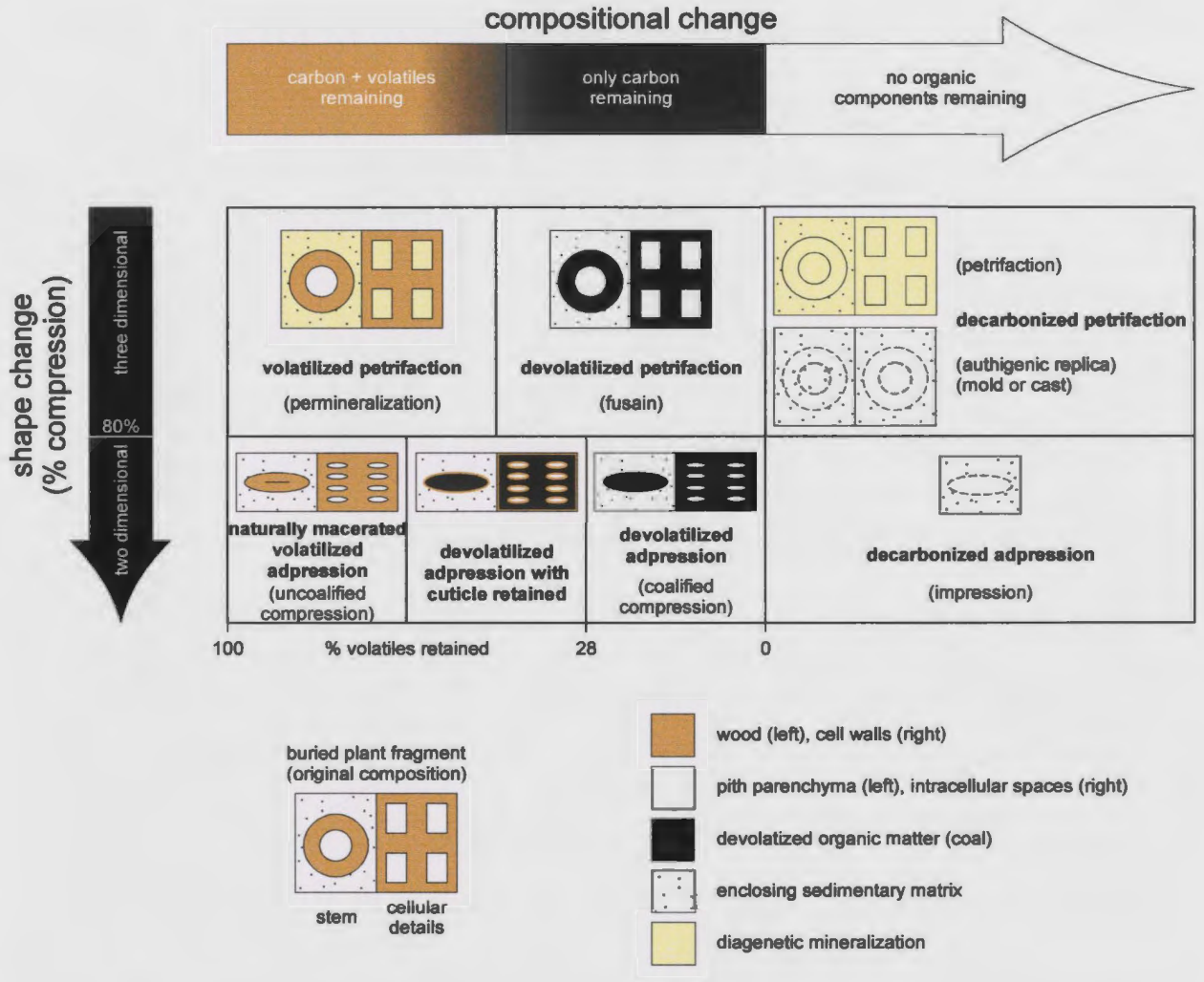

Figure 3.1. Classification of preservational modes of plant fossils based on comparison of shape change and chemical composition. Modified from Bateman (1991), incorporating classification of Schopf (1975) and data from Barthel (1962).

pyritization of certain parts of devolatilized adpressions, particularly vascular tissues of axes or laminae, is also quite common. Moreover, partial pyritization of a single neuropterid pinnule on slab 30-190 has resulted in the exceptional preservation of fine epidermal cellular details of the lamina (Fig. 3.2.1).

Not surprisingly, fossils entombed in mudstones are considerably better preserved than those recovered from siltstones or fine grained sandstones. This differential preservation emphasizes the necessity for potential fossils to be buried rapidly and under anoxic conditions so that oxidation and bacterial or fungal biodegradation of plant tissues is inhibited or minimized (Schopf 1975; Bateman 1991). Oxidation (and eventual destruction) of potential plant fossils is accelerated in coarser grained sediments because of a corresponding increase in exposure to oxidizing mediums (Retallack 1990). Kryshtofovich (1944) coined the term "phytoleim" to describe the black, brittle, coalified and compressed tissue that typifies devolatilized adpressions. Phytolemmas are typically internally amorphous, although when entombing sediments are thermally immature and less than 72 % of volatiles have been driven off (Barthel 1962), a resistant cuticular envelope persists (Fig. 3.1). A fossil cuticle constitutes a thin but comparatively very durable mixture of the biopolymer cutan plus waxes that enveloped the plant, and hence represents a taxonomically meaningful replica of the external cellular morphology of the epidermis (Barthel 1962; Bateman 1991; Tegelaar et al. 1991). It is worthwhile noting at this point that the presence of cuticular material, which comprises volatiles, within "devolatilized" adpressions calls into question the validity of the terminology used in Bateman's (1991) plant fossil classification (Fig. 3.1) – it is evident that a more

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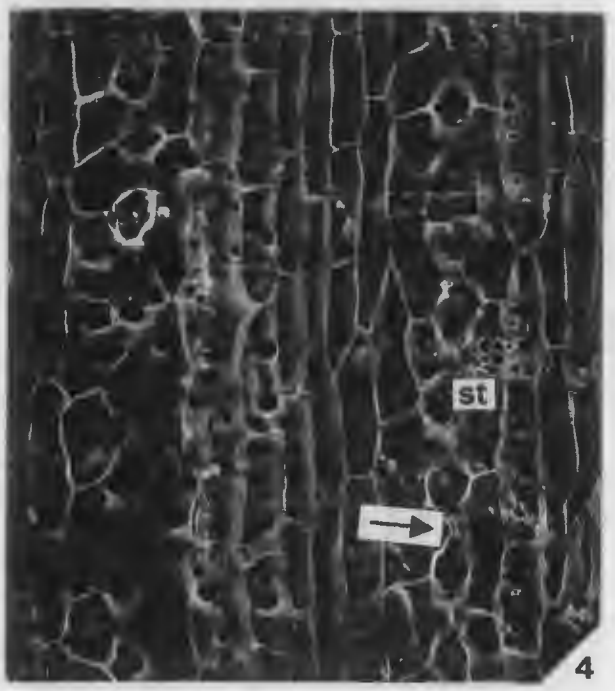

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(*previous page*) Figure 3.2. (1.) Excellent preservation of fine epidermal cellular details by partial pyritization of *Neuropteris semireticulata* pinnule (30-190) (x 22). (2.) Transmitted light microphotograph of adaxial cuticle of *Cordaites* sp. leaf demonstrating details of epidermal cell morphologies (x 270); stomatal rows (sr) and stomata (s). (3.) SEM image of abaxial cuticle of *Cordaites* sp. leaf (30-228) (x 300); stomata (arrow). (4.) Adaxial cuticle (30-228) (x 350); stomata (arrow) and spongy sclerotic tissue (st).

appropriate term is necessary for those "devolatilized" adpressions that have actually retained volatiles in the form of cuticles.

Recent studies of cuticles, particularly of medullosan pteridosperms but including *Cordaites* spp. and sphenophylls, have been monumental in establishing the taxonomic position and paleoecology of numerous taxa (e.g., Barthel 1962, 1997; Reihman and Schabilion 1978; Mickle and Rothwell 1982; Schabilion and Reihman 1985; Cleal and Zodrow 1989; Cleal et al. 1990; Cleal and Shute 1991, 1992; Kerp and Barthel 1993; Zodrow and Cleal 1993; Šimunek, in press). Given that strata at Blanche Brook evidently have very low thermal maturities, reconnaissance attempts were made to determine the quality of preservation of cuticles that presumably exist within coalified phytolemmas (Appendix 1) – samples were taken from devolatilized adpressions of previously identified pteridosperm, cordaitean and pecopterid foliage collected from localities BB-14, BB-25 and BB-30. Similarly, yellowish brown "naturally macerated" volatilized neuropteroid adpressions from locality BB-14 were prepared by the same method to either validate or negate the postulation that these fossils simply constitute cuticular material that has experienced limited coalification. It must be noted, though, that descriptions and taxonomic identification of recovered cuticles based on epidermal

Figure 3.3. *Neuropteris semireticulata* pinnules that have been macerated in Schulze's Reagent, but not yet treated with ammonium hydroxide (see Appendix 1) (x 8).

Figure 3.4. Sandstone infilled pith (p) in tree petrifaction from locality BB-23. Notebook ca. 17.8 cm long.

characteristics was not intended, as such an investigation is well beyond the scope of the present study.

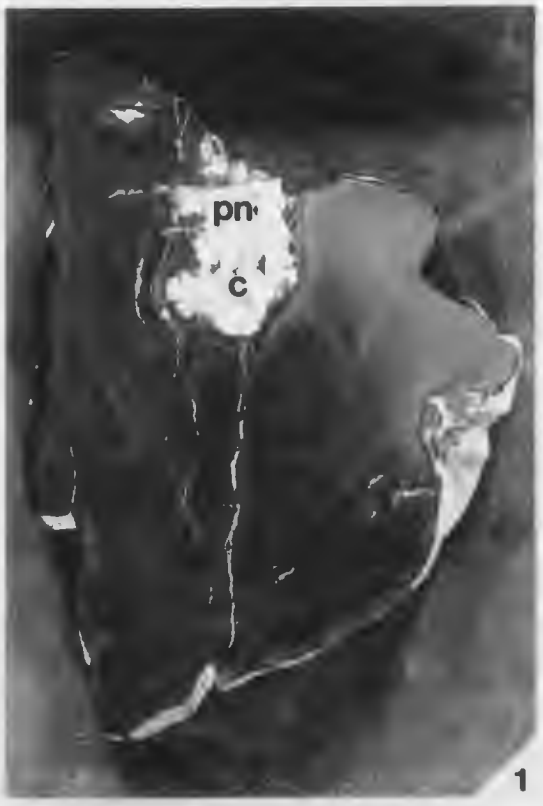
The results of this test have been very encouraging. Very well preserved cuticles showing considerable detail of external, epidermal morphologies were procured from devolatilized adpressions of *Neuropteris semireticulata* Josten (Fig. 3.3; Pl. 23, Fig. 9) and *Cordaites* spp. (Figs. 3.2.2, 3.2.3 & 3.2.4; Pl. 25, Fig. 6) from locality BB-30. Somewhat less well preserved cuticles were recovered from devolatilized adpressions of *Laveineopteris rarinervis* (Bunbury) Cleal et al. (Pl. 19, Fig. 4) and "naturally macerated" volatilized adpressions of cf. *Laveineopteris tenuifolia* (Sternberg) Cleal et al. (Pl. 20, Fig. 4). Conversely, and similarly to other localities within the Euramerian Paleokingdom, pecopterids yielded only poorly preserved, fragmentary and unidentifiable cuticle fragments [see Zodrow (1993) for fuller discussion]. This differential preservation may in fact be related to the original (i.e., prior to fossilization) chemical composition of the cuticles. For example, Tegelaar et al. (1991) suggested that cuticles with a significant component of the biopolymer cutan in their original cuticular matrix will endure diagenetic processes better than those predominated by the biopolyester cutin.

In most cases, pteridosperm and cordaitean leaf cuticles are well enough preserved that both adaxial (upper) and abaxial (lower) surfaces can be teased apart. Examination of these cuticles by both SEM and transmitted light microscopy revealed that considerable detail of epidermal cells, including stomatal apparatuses, and sclerotic tissues is preserved on both upper and lower cuticle surfaces (Figs. 3.2.3 & 3.2.4).

The excellent quality of preservation of cuticles from adpressed pteridosperm and cordaitean foliage substantiates earlier conclusions, based on vitrinite reflectance (Hacquebard and Donaldson 1970; Hyde et al. 1991), clay mineral assemblages and illite crystallinity (Hyde et al. 1985), that strata of the "undivided Barachois Group" in the northern part of the Bay St. George Basin are thermally immature (i.e., at least 28% of volatile components are retained in phytolemmas). Preliminary analyses of cuticles by SEM and transmitted light microscopy certainly indicate that further cuticular studies at Blanche Brook are warranted. As a case in point, the opportunity for further investigation was seized by E.L. Zodrow of University College of Cape Breton, Nova Scotia, who has included cordaitean leaf cuticles recovered from the BBA in ongoing studies (with the author) involving cuticle-based taxonomy and chemotaxonomy of *Cordaites* spp. leaves from various localities within the Maritimes Basin.

3.2 Tree Petrifactions

Large tree petrifactions contained within conglomerates and sandstones of the coarse (channel) lithofacies are preserved as light to dark (and sometimes slightly purplish) brown, volatilized petrifactions that generally are partially compressed but may be essentially unflattened (Figs. 3.4, 6.10). The three dimensionality indicates that mineral enriched fluids infilled intracellular spaces within the waterlogged trees very soon [only a few months according to Schopf (1975, p. 34)] after rapid burial under anoxic conditions. When the central pith is preserved, it typically is infilled with sandstone or pebbly sandstone (Fig. 3.4), or less commonly, with irregularly shaped, nodular pyrite (Fig. 3.5.1). XRD analysis, combined with examination of thin sections under cross-nicols,



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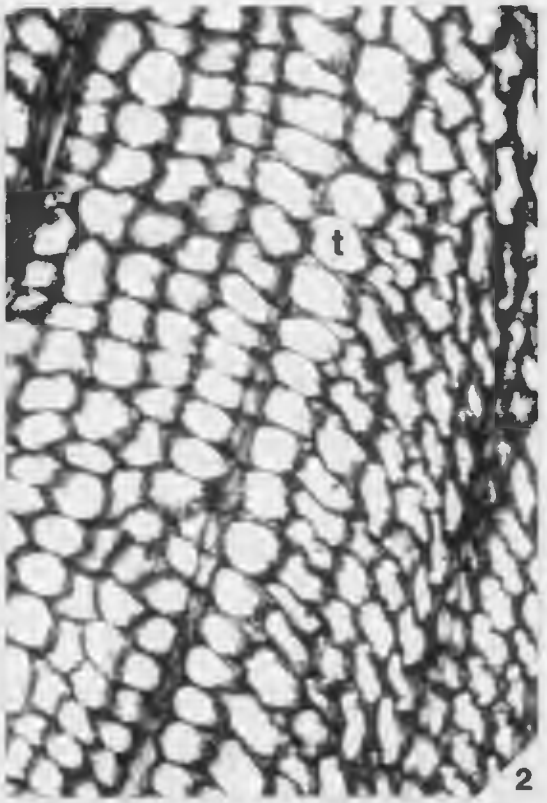

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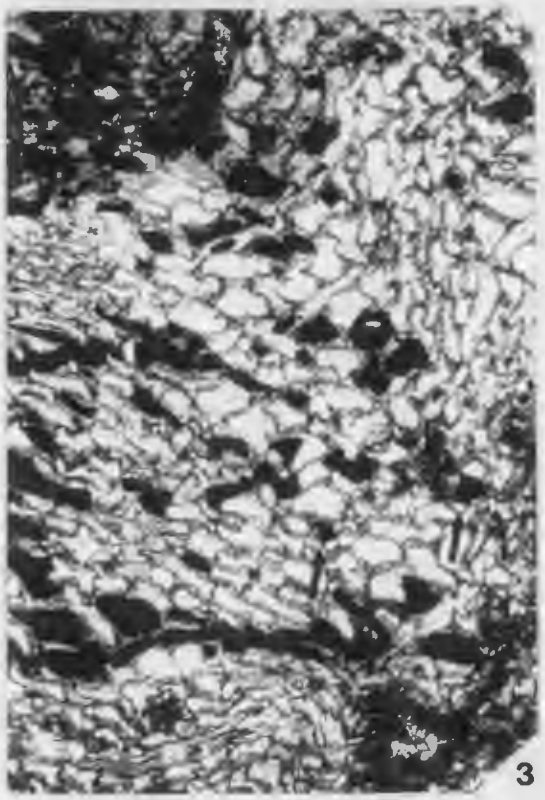
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(*previous page*) Figure 3.5. (1.) Slabbed and polished tree petrifaction *(Dadoxylon* sp.) cut in transverse plane showing results of plastic-type deformation during compression of secondary xylem (wood). Also note large pyrite nodule infilling pith (pn), fracture within nodule infilled by moderately coarse grained calcite (c), and smaller fractures (f) infilled by very fine grained calcite (x 1). (2.) Progressive loss of intracellular space in tracheids (t) resulting from compression, bending and eventual breakage of cell walls (23-2) (x 125). (3.) Very fine grained pyrite within wood (23-1), showing that some subhedral to euhedral grains evidently grew within intracellular spaces prior to enclosure by later stage calcite permineralization (arrows) (x 125). (4.) Complete collapse of cell walls of tracheids due to intense compression. Brittle deformation resulted in fractures in wood infilled with coaly matter (23-1) (x 125).

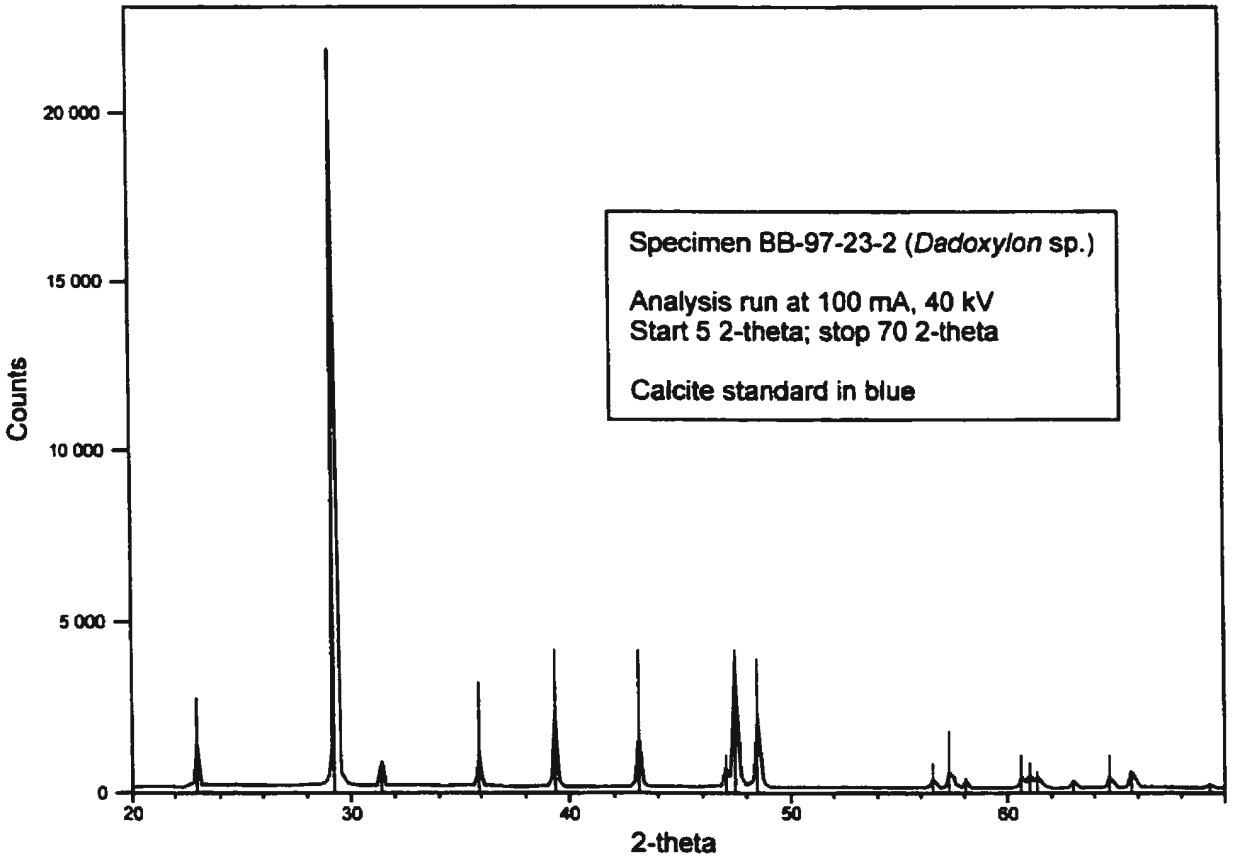


Figure 3.6. X-ray diffraction spectrum from sample of tree petrifaction (*Dadoxylon* sp.), which is entirely compatible with calcite standard. This demonstrates that fine cellular details have been pervasively permineralized by calcite - the lack of backscatter indicates that little organic matter has been retained.

revealed that calcite is the predominant permineralizing agent responsible for fossilization of these tree petrifactions (Fig. 3.6). The lack of backscatter on the XRD plot suggests that very little amorphous, organic volatiles are present in the sample. However, transmitted light microscopy clearly indicates that at least some brown, organic material has been retained within cell walls, which justifies calling these fossils volatilized petrifactions (*sensu* Bateman 1991; Fig. 3.1).

Analysis of four thin sections from three petrifactions and a polished hand sample of pycnoxylic wood (secondary xylem referable to *Dadoxylon* sp. and very likely of cordaitean affinity, see p. 127-129) indicates that fossilization probably occurred in at least five stages. Although such "degrees of fossilization" are not discrete, and may actually be in part contemporaneous, an attempt has been made to arrange the stages in chronological order:

1. Very soon after burial, waterlogged trees were differentially compressed and deformed somewhat plastically, with the consequent loss of intracellular space varying considerably (0 to 100%) even within a single thin section. With increasing compaction, cell walls of tracheids (initially circular or equidimensional in cross section; Fig. 3.5.2) were first distorted by bending and then eventually broke before completely collapsing onto adjacent tracheids (Fig. 3.5.4).
2. Pyrite evidently crystallized very quickly under anoxic conditions in irregularly shaped blotches or as nodules (generally on mm but occasionally on cm scale) that either completely replaced patches of wood (Fig. 3.5.1), or infilled intracellular spaces without disrupting cell walls (see Matten 1973). Extremely fine pyrite grains,

some of which are euhedral to subhedral, are also disseminated throughout the wood (Fig. 3.5.3).

3. Light to medium brown cell walls of both tracheids and vascular ray cells (Fig. 3.5.2) were permineralized and embedded in extremely fine grained (cryptocrystalline?) calcite.
4. Intracellular spaces of tracheids and vascular ray cells(?) were pervasively (>99%) infilled by colorless to yellowish, very fine grained calcite. The timing of pyrite versus calcite crystallization can be confidently established because pyrite nodules may be crosscut and fractured by medium to coarse grained calcite cement (Fig. 3.5.1), and because euhedral pyrite grains within intracellular spaces are completely enclosed by later stage calcite permineralization (Fig. 3.5.3).
5. Fractures that crosscut permineralized wood likely resulted from continued compression and brittle deformation, and either contain black, blocky coaly material (Fig. 3.5.4) or were infilled by fine grained calcite (Fig. 3.5.1) or pyrite.

Chapter 4 – Descriptive Taxonomy

4.1 A Note on Synonymy Lists

The synonymy lists preceding systematic descriptions of many taxa in this chapter represent a list of illustrations (either line drawings, artistic renditions or photographs) of specimens from other localities, in whatever literature was available to the author, which are morphologically identical to (or at least compare very closely with) material from the Blanche Brook Assemblage. Comparisons that are more tentative or doubtful are marked with an asterisk (*) after the publication date.

4.2 Division LYCOPHYTA

Order LEPIDODENDRALES

Form-genus *Cyperites* Lindley and Hutton, 1833

cf. *Cyperites bicarinatus* Lindley and Hutton, 1833

Pl. 1, Figs. 1 to 6

1944 *Lepidophyllum* sp., Bell, pp. 96-97; pl. 59, fig. 2.

1983 *Cyperites bicarinatus*, Rex, pp. 81-82; pl. 4, figs. 1, 2.

MATERIAL AND OCCURRENCE – Abundant isolated leaf fragments from BB-30 and BB-32 preserved as (occasionally partially pyritized) devolatilized adpressions.

DESCRIPTION – Leaves linear, tapering slightly distally, up to 17 cm long (bases nor apices preserved), 1.4 to 9.0 mm wide, abaxial surface carinate, adaxial surface with median furrow, lateral margins entire; median furrow (Pl. 1, Figs. 5, 6) 0.4 to 0.6 mm

wide, bordered laterally by rounded, longitudinal ridges or grooves; carinae (Pl. 1, Figs. 2 to 4) prominent, longitudinally striated, trapezoidal and truncate to slightly rounded, 0.2 to 0.5 mm wide, carina:leaf width ratio 0.09 to 0.27 (ave. 0.16, n=15).

REMARKS – Although vertical sections could not be made to determine whether leaves have the characteristic "butterfly" shape (in transverse section) that Rex (1983) maintains are diagnostic of *Cyperites* sp., the exclusively isolated linear lycopsid leaves otherwise conform to her emended diagnosis. The entire lateral margins on all specimens of the BBA strongly suggests reference to *C. bicarinatus*, rather than to *C. ciliatus*, which has ciliated margins (Crookall 1966).

Arborescent lycopsid debris at BB-32 is entirely of sigillarian origin, which suggests that markedly (and consistently) broader specimens of cf. *Cyperites bicarinatus* from that locality (Pl. 1, Figs 5, 6) represent leaves of *Sigillaria*; narrow leaves from BB-30 (Pl. 1, Figs. 1 to 4) are associated only with "*Lepidodendron*" sp. cf. "*L.*" *bretonense*.

Lepidodendron Sternberg, 1820

"*Lepidodendron*" sp. cf. "*L.*" *bretonense* Bell, 1962

Fig. 4.1.1 (p. 42); Pl. 2, Figs. 1 to 9

1938 *Lepidodendron dichotomum* var. *bretonensis*, Bell, pp. 92-93; pl. 95, figs. 5-9; pl. 96, fig. 1; pl. 97, fig. 4.

1940* *Lepidodendron dichotomum*, Bell, p. 122; pl. 7, fig.4.

1944 *Lepidodendron dichotomum* var. *bretonensis*, Bell, p. 89; pl. 45, fig. 3.

1962 *Lepidodendron bretonense*, Bell, pp. 53-54; pl. 47, figs. 5, 6; pl. 48, figs. 4, 6.

1966 *Lepidodendron bretonense*, Bell; pl. 21, fig. 5.

1980 *Lepidodendron bretonense*, Zodrow and McCandlish, p.80; pl. 116, fig. 1; pl. 118, figs. 1?, 2.

1985* *Lepidodendron bretonense*, Wnuk, pp. 169-173; pl. 2, figs. 7, 8.

MATERIAL AND OCCURRENCE - Ten thin axial fragments from BB-30 preserved as devolatilized and decarbonized adpressions.

DESCRIPTION – Axes up to 15.5 cm long and 3.1 cm wide, straight to gently curved, distal portions may dichotomize (Pl. 2, Fig. 5); leaf cushions asymmetrical, 5.1 to 10.2 mm long, 2.3 to 3.8 wide, L:W ratio 1.44 to 3.45, outlines variable depending on maturity of stem; immature cushions (Pl. 2, Figs. 3, 4, 6, 9) contiguous, crowded, quadrilateral, rhomboidal or napiform (i.e., L:W ratio ca. 1), lateral margins obtusely rounded to curved, upper angles acutely or obtusely pointed (rarely rounded), lower angles acutely pointed, slightly curved to adjoin underlying cushion; mature cushions (Pl. 2, Figs. 7, 8) elongate, fusiform (i.e., increasing L:W ratio), lateral margins gently curved, upper and lower angles more acute and oppositely curved, separated by 0.4 to 1.2 mm wide, wrinkled or longitudinally striated interareas (Pl. 2, Fig. 7); leaf scars nearly equidimensional, situated in upper half of cushion (occasionally closer to one side), 1.4 to 2.2 mm long, 1.6 to 2.4 mm wide, L:W ratio 0.70 to 1.36 (ave. 0.96, n=16), upper and lower angles obtusely rounded, lateral angles narrowly rounded; cicatricules (Fig. 4.1.1; Pl. 2, Fig. 9) occupy lower half of leaf scar, with centrally located, elliptical vascular trace (ca. 0.4 mm long, 0.3 mm wide) either in line with or slightly lower than laterally

located, circular foliar parichnos traces (ca. 0.3 mm diameter); upper corner of upper field occupied by flat, triangular depression (Pl. 2, Fig. 4; Fig. 4.1.1), remainder of upper field elevated, with upper side of leaf scar more inflated than lower resulting in leaf scar that is inclined somewhat downward (Pl. 2, Fig. 4); lower field usually smooth but sometimes with faint keel (Pl. 2, Fig. 8) (especially in more mature cushions).

REMARKS – Most specimens in the BBA represent immature, thin axes, and thus most closely resemble immature stems or determinate branches described by Bell (1938, p. 92-93) and Wnuk (1985); more mature stem fragments, characterized by narrow striated interareas, are not common and are poorly preserved.

Despite the quality of preservation, none of the leaf cushions examined exhibited a ligule pit above the leaf scar or infrafoliar parichnos traces below the leaf scar. The absence of infrafoliar parichnos excludes the stem fragments from true *Lepidodendron* (*sensu* DiMichele 1983, 1985), and rather they conform fully to the diagnosis of the genus *Diaphorodendron* introduced by DiMichele (1985) for a distinct group of arborescent lycopsids preserved as petrifactions. No formal name has yet been introduced for equivalent fossils preserved as adpressions, and following the lead of DiMichele and Phillips (1994, p. 59), the material described herein is referred to "*Lepidodendron*" *bretonense*. According to these authors, "*L.*" *bretonense* likely represents the adpression equivalent of the petrifaction *Diaphorodendron scleroticum*. It should be noted that in the Diaphorodendraceae the ligule aperture opens behind the leaf scar and is partially covered by a plication (DiMichele 1981), which explains the apparent absence of ligule pits in material from the BBA.

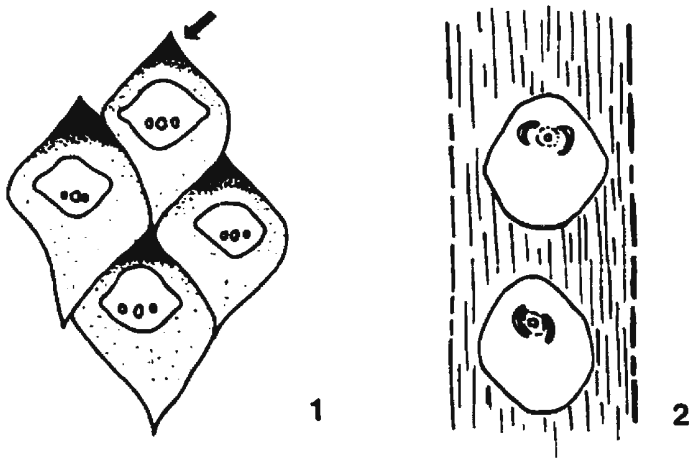


Figure 4.1. Schematic line drawings of lycopsid leaf attachment structures. (1.) Immature leaf cushions of "*Lepidodendron*" sp. cf. "*L.*" *bretonense* with flat, triangular shaped depression occupying upper corner of upper field (arrow) and faint keel in lower field; central vascular cicatrix in lower half of leaf scars flanked by foliar parichnos cicatrices; BB-94-30-6, x5. (2.) Ovate leaf scars of *Sigillaria* sp. with inflated central vascular cicatrix flanked by lunate, foliar parichnos cicatrices; BB-96-32-16, x2.

Bell (1938, p. 93; 1944, p. 89; Bell 1962, p. 55) observed in the Maritimes Basin the frequent association of "*L.*" *bretonense* with the sporophyll *Lepidostrobophyllum triangulare* (=? *Lepidostrobus mintoensis* of Bell 1962) , and considered that the cone-scales and axes likely belonged to the same plant. The fact that *L. triangulare* makes up part of the BBA supports reference of axial fragments to "*L.*" *bretonense*, and corroborates Bell's earlier assumptions regarding whole-plant affinities. Additionally, *Lepidostrobophyllum* spp. sporophylls are thought to have been derived from the desegregation of the cone *Achlamydocarpon varius*. (Liesman and Phillips 1979; Phillips 1979; Stewart and Rothwell 1993), which occupied lateral branches that arose near the tips of vegetative branches of *Diaphorodendron* spp. (DiMichele 1981, 1983, 1985).

This provides further support for the affinity of "*L.*" *bretonense* (=*Diaphorodendron scleroticum*) and *L. triangulare*.

Form-genus *Lepidostrobophyllum* (Hirmer) Allen, 1966

***Lepidostrobophyllum alatum* Boulter, 1968**

Pl. 1, Figs. 7 to 12, 14

1938* *Lepidostrobophyllum lanceolatum* var. *constrictum*, Bell, pp. 97-98; pl. 98, figs. 7, 10, 11(?).

1968 *Lepidostrobophyllum alatum*, Boulter, pp. 448-450; text-figs. 1, 2 (p. 446); pl. 83, figs. 1-4; pl. 84, figs. 1-5.

MATERIAL AND OCCURRENCE – Abundant isolated sporophylls from BB-30 preserved as (occasionally partially pyritized) devolatilized and decarbonized adpressions; one devolatilized specimen represents cone fragment with attached sporophylls (Pl. 1, Fig. 8).

DESCRIPTION – Sporophyll laminae lanceolate, subovate or elongate-triangular, 10.3 to 30.5 mm long (ave. 23.7 mm, n=34), 5.1 to 9.7 mm wide (ave. 7.4 mm, n=36), widest at contact with pedicel; lateral margins entire, straight to slightly convex, either gradually approaching each other or parallel sided to approximately half way up blade before converging to acuminate point, infrequently shallowly constricted about 1/4 distance up lamina (Pl. 1, Figs. 9, 12); lateral angles acute, rounded and flush with pedicel, but occasionally hastate and project outwards; midvein (rib on adaxial surface, furrow on abaxial) extends entire length of blade, may have faint longitudinal striations, ca. 0.2 to

0.9 mm wide (ave. 0.6 mm, n=19) at proximal edge, narrowing distally; pedicels subovate to subtriangular or cuneate with convex lateral margins, 5.4 to 9.0 mm long (ave. 7.7 mm, n=27), 3.6 to 8.3 mm wide (ave. 6.7 mm, n=26), widest at contact with blade, narrowing proximally; abaxial surface with prominent carina, 0.1 to 0.8 mm wide at proximal end, expanding distally; edges of pedicel alate, alations hair-like, ca. 0.8 to 1.4 mm long.

REMARKS – The majority of isolated sporophylls in the BBA can be referred to *Lepidostrobophyllum alatum* based on the diagnostic alate rim (Pl. 1, Fig. 11) around the pedicel for which it is named (Boulter 1968, pl. 84, fig. 4), and in part on overall sporophyll morphology (Boulter 1968; Cleal and Thomas 1994). Specimens from Blanche Brook bear a striking resemblance to the reconstruction by Phillips (1979, fig. 1.D, p. 245) of a megasporangium-bearing sporophyll from the monosporangiate cone *Achlamydocarpon varius*, which was borne by *Diaphorodendron* spp. trees (DiMichele 1983, 1985). According to Leisman and Phillips (1979), sporophylls from *A. varius* had alate pedicels and a very prominent heel on the abaxial side of the pedicel/lamina contact, which conforms fully with the present material.

Blades of *L. alatum* are considerably larger and longer than those of *L. triangulare*, the other sporophyll recovered from Blanche Brook. Additionally, pedicels of the former generally are subovate, while those of *L. triangulare* are smaller, distinctly cuneate with straight lateral margins, and lack alate rims.

Lepidostrobophyllum triangulare (Zeiller) Bell, 1938

Pl. 1, figs. 10, 13, 15, 16

1938 *Lepidostrobophyllum triangulare*, Bell, pp. 95-96; pl. 97, figs. 5, 6.

1966 *Lepidostrobophyllum triangulare*, Bell, pl. 35, fig. 1.

1966* *Lepidostrobophyllum mintoensis*, Bell, pl. 19, fig. 3.

1966 *Lepidostrobus triangularis*, Crookall, pp. 511-512; text-fig. 145f (p. 497); pl. 102, fig. 11.

MATERIAL AND OCCURRENCE – Moderately abundant isolated sporophylls from BB-30 and BB-32 preserved as devolatilized and decarbonized adpressions; one specimen represents cone fragment with attached sporophylls.

DESCRIPTION – Cone axis ca. 11.0 mm in diameter, bearing overlapping cone scales; sporophyll laminae triangular or cuneate, somewhat hastate, 8.4 to 11.8 mm long (ave. 10.0 mm, n=14), 5.2 to 7.4 mm wide at base (ave. 6.6 mm, n=14); lateral margins essentially straight, diverging rapidly to acute apex; lateral angles acute or acutely rounded, project beyond blade/pedicel contact, may be turned inward to point proximally; midvein not prominent, ca. 0.3 to 0.6 mm wide at base, narrowing distally; pedicels cuneate, straight lateral margins, 2.2 to 7.8 mm long (ave. 5.5 mm, n=12), 1.8 to 5.1 mm wide (ave. 3.1 mm, n=12), widest at contact with blade, narrowing proximally; abaxial surface with carina ca. 0.1 mm wide at proximal end, expanding distally to 0.6 mm near contact with blade.

REMARKS – The cone fragment (Pl. 1, Fig. 13) is tentatively referred to *L. triangulare* based primarily on size and morphology of attached sporophyll blades. A sporophyll figured as *Lepidostrobophyllum mintoensis* by Bell (1966) compares closely with *L. triangulare* (conspecific?), although Bell (1962) noted that *L. mintoensis* had narrower and shorter pedicels and lacked projecting lateral angles. Boulter (1968) noted similarities between *L. triangulare* and small adpressions of *L. alatum* (see pl. 84, fig. 5), but concluded they were not synonymous based on differences of the pedicel.

Two specimens (30-18 and 32-11) have blades with distinctly convex lateral margins and more acutely pointed apices than most specimens of *L. triangulare*. They may compare more closely with specimens of *Lepidostrobophyllum jennyi* (see Bell 1938, pl. 98, figs. 2, 3; *Lepidostrobus anthemis* of Crookall 1966, p. 508), or *Lepidostrobus goodei* (Crookall 1966, text-figs. 145l, m; pl. 101, fig. 12). However, Bell (1940) noted that *L. triangulare* and *L. jennyi* compare closely and may in fact be conspecific.

Bell (1962) considered that *L. mintoensis* (=*L. triangulare sensu* Bell 1938, p. 96) sporophylls may have been derived from "*Lepidodendron*" *bretonense* trees, which probably are the adpression equivalents of *Diaphorodendron scleroticum* petrifactions (DiMichele and Phillips 1994). The affinity between "*L.*" *bretonense* and *L. triangulare* is supported by the assertion of DiMichele (1983, 1985) that *Diaphorodendron* spp. trees bore monosporangiate cones (*A. varius*) that desegregated to form *Lepidostrobophyllum* spp. sporophylls (Stewart and Rothwell 1993).

It is worth noting that, despite the obvious morphological differences between *L. alatum* and *L. triangulare*, both species are purported to have made up the cone *A. varius*. This apparent heteromorphy could be explained by the fact that two forms of the taxon are known from the fossil record – a megasporangiate (female) cone bearing *Cystosporites varius* megaspores on comparatively large sporophylls, and a microsporangiate (male) cone with *Cappasporites distortus* microspores and relatively small sporophylls (Courvoisier and Phillips 1975; Leisman and Phillips 1979; Phillips 1979). Hence, it is possible that *L. alatum* was derived from the megasporangiate cones of *A. varius*, while *L. triangulare* represents smaller sporophylls from microsporangiate cones.

Sigillaria Brongniart, 1822

Sigillaria sp.

Fig. 4.1.2 (p. 42); Pl. 3, Figs. 4, 5

MATERIAL AND OCCURRENCE – Single axis fragment from BB-32 preserved as devolatilized adpression.

DESCRIPTION – Axis flattened, ca. 4.0 cm wide, ca. 11.0 cm long; surface characterized by convex ribs and intervening straight to slightly undulate shallow furrows; ribs finely striate, ca. 12.2 to 12.8 mm wide, bearing leaf scars 2.1 to 2.8 mm apart (top of scar to base of next higher scar), 10.7 to 13.2 mm apart (cicatrix to cicatrix); leaf scars slightly elevated from stem surface, ovate, oval or nearly equidimensional (i.e., semicircular), bases fairly flat to bluntly rounded, apices obtusely rounded, lateral

margins convex, 8.7 to 10.5 mm long, 7.2 to 8.5 mm wide (broadest 1/3 to 1/2 way from base), L:W ratio 1.09 to 1.42; foliar cicatricules (Fig. 4.1.2; Pl. 3, Fig. 5) punctiform, situated between 1/2 to 2/3 way from scar base; central vascular cicatrix elevated, ca. 0.48 to 0.65 mm in diameter; lateral parichnos cicatricules lunate, somewhat elevated, 1.5 to 2.1 mm long.

REMARKS – The single specimen upon which this description is based is small and not particularly well preserved, and thus several taxonomically significant, morphological features could not be discerned. However, in comparison with the non-biological classification proposed for *Sigillaria* based entirely on external morphology of bark (see excellent summary in Crookall 1966, p. 357-359; also Josten 1991, fig. 92, p. 157), the specimen can confidently referred to the Eusigillariae, a category characterized by ribbed stems. More specifically, the specimen likely can be included in the *Eurhytidolepis* subsection of the *Rhytidolepis* section; the *Eurhytidolepis* subsection is characterized by leaf scars disposed on vertical ribs that have essentially straight lateral margins.

Form-genus *Sigillariostrobus* (Schimper) Feistmantel, 1876

***Sigillariostrobus rhombibracteatus* Kidston, 1897**

Pl. 3, Figs. 6, 7

1966 *Sigillariostrobus rhombibracteatus*, Crookall, pp. 542-544; pl. 103, figs. 11, 12.

MATERIAL AND OCCURRENCE – Single isolated sporophyll from BB-32 preserved as devolatilized adpression.

DESCRIPTION – Sporophyll rhomboidal lanceolate, ca. 7.8 mm long, 3.8 mm wide at broadest point, base rhomboidal, apex acute and elongate; lateral margins concave, bearing enations or "cilia" in near base; enations short, stout, 73 to 94 μm long, 52 to 59 μm wide at base, apices bluntly rounded.

REMARKS – The isolated sporophyll can be confidently referred to the form-genus *Sigillariostrobus*, which represents sigillarian cone fragments, based on the rhomboidal lanceolate shape and ciliate lateral margins (Pl. 3, Fig. 7) of the sterile bract. The specimen closely resembles isolated *S. rhombibracteatus* sporophylls figured by Crookall (1966), and conforms well to his description. The fact that abundant megaspores referable to *Tuberculatisporites mamillarius* were recovered from the same locality (BB-32) strongly supports assignment of the sporophyll to *S. rhombibracteatus*, as these same megaspores were successfully isolated by Chaloner (1953) from cones assigned to *S. rhombibracteatus*.

Form-genus *Stigmaria* Brongniart, 1822

***Stigmaria ficoides* (Sternberg) Brongniart, 1822**

Pl. 3, Figs. 1, 2

1938 *Stigmaria ficoides*, Bell, p. 103; pl. 105, fig. 8.

1962 *Stigmaria ficoides*, Bell, p. 56.

1966 *Stigmaria ficoides*, Bell, pl. 9, fig. 2.

1966 *Stigmaria ficoides*, Crookall, pp. 549-556; text-fig. 156 (p. 555); pl. 105, figs. 1, 2.

1966 *Stigmaria* sp., Crookall, pl. 104, fig. 4; pl. 105, fig. 3.

1969 *Stigmaria ficoides*, Darrah, p. 81; pl. 27, fig. 3.

1977 *Stigmaria ficoides*, Remy and Remy, p. 344; fig. 208b (p. 345).

1991 *Stigmaria ficoides*, Josten, p. 189; table 11(p. 188); pl. 75, figs. 1, 1a; pl. 76, fig. 1.

MATERIAL AND OCCURRENCE – Seven rhizophore fragments collected from BB-14, BB-30 and BB-32 (but ubiquitous taxon, particularly in grey coal-bearing strata), some with attached lateral appendages, preserved as devolatilized or decarbonized adpressions, or as partially decarbonized petrifactions. Attached or isolated lateral organs preserved as devolatilized adpressions, often with partially pyritized midveins.

DESCRIPTION – Rhizophores flattened, 4.5 to 8.6 cm wide, not exceeding 19.9 cm long; axial surfaces more or less smooth, occasionally with somewhat irregular, low relief, longitudinal ribs 0.9 to 1.6 mm apart, with spirally arranged rows of elevated surface scars; scars circular, ca. 1.2 to 5.9 mm in diameter, with raised rim surrounding circular depression, cored by single elevated vascular cicatrix (0.3 to 1.0 mm diameter); lateral organs (appendages) isolated or emanate from surface scars perpendicular to rhizophore, ribbon like and unbranched, infrequently fork distally (Pl. 3, Fig. 2), 2.5 to 6.5 mm wide (gradually tapering distally), entire but undulatory lateral margins, with single more or less centrally positioned midvein 0.3 to 0.6 mm wide.

REMARKS – *Stigmaria ficoides* is a widely recognized taxon that represents subterranean rooting organs of arborescent lepidodendroid lycopods (Thomas 1978),

although this stigmarian system may be exclusive to members of the Lepidodendraceae (Frankenberg and Eggert 1969). The typically smooth rhizophore surface and spiral distribution of surface scars closely resembles specimens of *S. ficoides* described and figured by numerous authors.

Low relief, longitudinal ribs on the surface of some specimens (Pl. 3, Fig. 1) are thought to represent imprints of radially(?) arranged internal structures of the axes, such as sclerenchymatous bands in the outer cortex (Crookall 1966; see also Eggert 1972, fig. 1, p. 96). Alternatively the ribs may in fact demonstrate wrinkling of the axial surface, a feature exhibited by *S. ficoides* var. *rugosa* (see Crookall 1966, pl. 104, fig. 2) or *S. rugulosa* (see Josten 1991, pl. 76, fig. 2), although the ribbing on these taxa is far more irregular and discontinuous.

Tuberculatisporites mamillarius (Bartlett) Potonié and Kremp 1955

Fig. 4.2 (p. 52)

1953 *Triletes mamillarius*, Chaloner, pp. 882-884, 896; figs. 1, 2 (p. 882).

1987 *Tuberculatisporites mamillarius*, Bartram; fig 3f, p. 192.

1988* *Tuberculatisporites mamillarius*, Traverse, fig. 1.1 (ab) (p. 3)

1996 *Tuberculatisporites mammillarius*, Scott and Hemsley, pl. 2, fig. 15.

MATERIAL AND OCCURRENCE – Abundant isolated, flattened megaspores adhering to surfaces of slabs collected from BB-32.

DESCRIPTION – Megaspores circular, conate (terminology of Playford and Dettmann 1996), 1.6 to 2.4 mm in diameter; contact area distinct with elevated curvatura perfecta

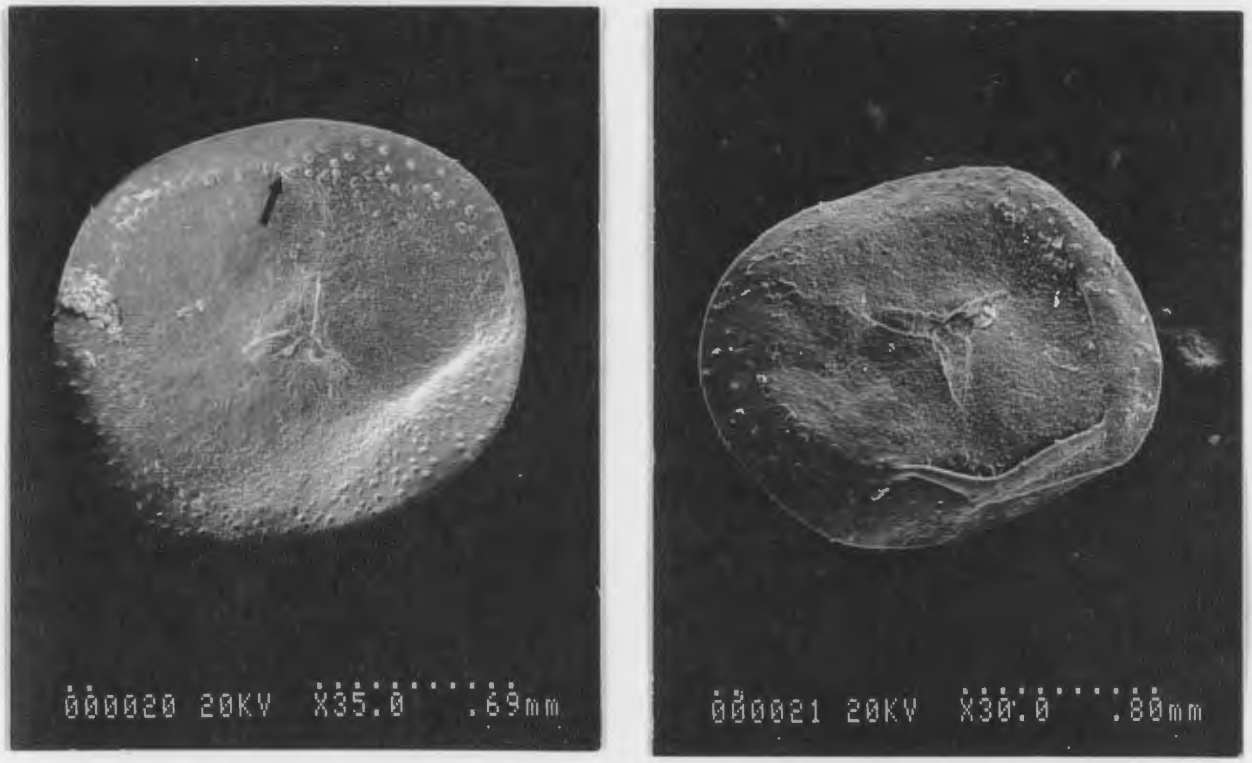


Figure 4.2. *Tuberculatisporites mamillarius* megaspores of sigillarian affinity; abundant conae comprise prominent curvatura perfecta (arrow), which separates granulate to finely conate contact area from conate proximal surface.

(Fig. 4.2), granulate to finely conate (or even reticulate?), laesurae of Y-mark slightly thickened and elevated; conae of contact area randomly disposed, ca. 12 to 17 μm in diameter; conae of distal and proximal surfaces randomly disposed but markedly abundant at curvatura perfecta, ca. 19 to 38 μm in diameter, 7 to 29 μm long, acuminate to acutely rounded.

REMARKS – Megaspores recovered from BB-32 are morphologically identical to those isolated by Chaloner (1953, 1986) from *Sigillariostrobus rhombibracteatus*, a cone of sigillarian affinity.

Lycopsid cone

Pl. 3, Fig. 3

MATERIAL AND OCCURRENCE – Single poorly preserved cone fragment in radial section from BB-32 preserved as partially devolatilized adpression.

DESCRIPTION – Cone 8.9 cm long, 2.8 cm wide; sporophylls overlapping, ca. 7.0 mm long, 0.6 to 0.8 mm wide in radial section.

REMARKS – Despite poor preservation, this specimen clearly represents a lycopsid cone fragment. No attempt was made to identify the adpression, as generic assignment depends primarily on whether the cones are monosporangiate (*Lepidostrobus*) or bisporangiate (*Flemingites*) (see Brack-Hanes and Thomas 1983, p. 131); a cone of greater length is necessary to determine whether it is homosporous or heterosporous.

Isolated lycopsid sporangia

Pl. 2, Figs. 10, 11

1966 Isolated lycopod sporangia, Crookall, pp. 522-523; pl. 99, figs. 7, 8.

1969* *Lepidocystis*, Darrah, p. 181; pl. 51, fig. 2.

MATERIAL AND OCCURRENCE – Two devolatilized adpressions from BB-25.

DESCRIPTION – Sporangia subrectangular to subtrapezoidal, angles rounded, ca. 15.2 to 16.0 mm long, 10.3 to 13.1 mm wide, one end markedly narrower; surface superficially smooth, actually with superfine granulate texture (Pl. 2, Fig. 10).

REMARKS – These plant organs have been included in the form-genus *Lepidocystis*, which Darrah (1969) considered to represent isolated lepidodendrid sporangium containing megaspores.

4.2 Division SPHENOPHYTA

Order SPHENOPHYLLALES

Sphenophyllum Brongniart, 1822

Sphenophyllum emarginatum (Brongniart) Brongniart, 1828

Fig. 4.3.1 (p. 57); Pl. 4, Figs. 1 to 9; Pl. 5, Figs. 1 to 7

1938 *Sphenophyllum emarginatum*, Bell, p. 89; pl. 93, figs. 1, 2, 3.

1958 *Sphenophyllum emarginatum*, Abbott, pp. 339-342; chart 3 (pp. 332-333); pl. 38, fig. 29; pl. 44, figs. 66, 68; pl. 45, fig. 72.

1962 *Sphenophyllum emarginatum*, Bell, pp. 46-47; pl. 44, figs. 1-4; pl. 56, fig. 1.

1966 *Sphenophyllum emarginatum*, Bell, pl. 29, fig. 2; pl. 36, figs. 5, 6.

1966 *Sphenophyllum emarginatum*, Storch, pp. 277-287; figs. 1, 15, 16e-g, 25; pl. 5, fig. 3; pl. 14, figs. 3, 4; pl. 15, figs. 1, 2; pl. 16, fig. 1, 2; pls. 17-22; pl. 23, fig. 1-3.

1969 *Sphenophyllum emarginatum*, Crookall, pp. 586-591; text-fig. 164 (p. 589); text-fig. 171b (p. 608); pl. 107, fig. 6.

1969 *Sphenophyllum emarginatum*, Darrah, pp. 177-178; pl. 55, fig. 1.

1977 *Sphenophyllum emarginatum*, Batenburg, pp. 81-95; text-fig. 4 (p. 89); text-fig. 5 (p. 91); pl. 2, figs. 3-6; pls. 3-6.

1977 *Sphenophyllum emarginatum*, Remy and Remy, pp. 386-387; pl. 237, figs. 1a-d.

1980 *Sphenophyllum emarginatum*, Storch, pp. 172-176; text-fig. 1 (p. 173); pl. 1, figs. 1-4; pl. 2, figs. 1, 2, 5, 6; pl. 3, fig. 1; pl. 4, figs. 1, 3; pl. 11, fig. 7.

1989 *Sphenophyllum emarginatum*, Zodrow, pp. 323-326; text-fig. 13 (p. 325); pl. 3, fig. 2; pl. 6, fig. 1.

1991 *Sphenophyllum emarginatum*, Josten, pp. 114-115; text-fig. 63 (p. 114); pl. 39, figs. 1, 1a, 2, 2a.

MATERIAL AND OCCURRENCE – Numerous specimens from BB-30 containing isolated whorls or occasionally branching axes [main, large and twigs (in descending order of ramification)]; preserved as devolatilized adpressions, or less commonly, as decarbonized or "naturally macerated" volatilized adpressions.

DESCRIPTION – Extremely heterophyllous, with morphologically dissimilar whorls of leaflets arising from main axes, large branches and twigs (described separately).

Main axes: Axes articulate, longitudinally striated, but smoother than large branches, bearing one (most common) or two (rare) twigs from any given node; internodes of similar dimensions throughout axis, 18.3 to 30.2 mm long, 3.2 to 5.7 mm wide; nodes slightly swollen, 4.2 to 6.8 mm wide, bearing whorls comprising indeterminate number of leaflets; leaflets linear (Pl. 4, Figs. 5, 9), undivided or divide once (or twice?) shortly after arising from node to form two (or four?) lobes, not exceeding 16.8 mm long, ca. 0.4 to 0.6 mm wide, containing single vein ca. 0.2 mm wide, terminating in acuminate or "hooked" arista (Pl. 4, Fig. 3).

Large branches: Axes articulate, with high amplitude longitudinal ribs 0.5 mm apart, single twig arising from any given node; internodes 2.0 to 2.9 mm wide, 5.3 to 12.4 mm long, shorten both to base and apex of branch; nodes slightly swollen, 2.7 to 3.2 mm wide, bearing whorls of indeterminate number of leaflets (at least 9 in one whorl); leaflets bipartite (Pl. 4, Fig. 9), morphologically akin to those on main axes, becoming successively less incised distally.

Twigs: Axes articulate, with longitudinal ribs ca. 0.5 to 0.8 mm apart, rarely with small, straight to apically curved, acuminate hairs ca. 0.3 mm long and 75μm wide at base; internodes 0.9 to 2.2 mm wide, 3.3 to 13.5 mm long, shorten both to base and apex of twig; nodes slightly swollen, 1.6 to 2.4 mm wide, each bearing whorl comprising 6 to 9 (rarely 10) morphologically similar leaflets of approximately equal length; leaflets of proximal verticils (Pl. 4, Fig. 1; Pl. 5, Fig. 7) stiff, arise decurrently, with single vein, ca. 6.6 mm long, 0.7 mm wide, broadest near middle, L:W ratio ca. 10.2; leaflets of distal verticils laminar, cuneate, 5.3 to 12.8 mm long, 1.1 to 6.3 mm wide at distal margin, L:W ratio 1.6 to 6.4 (ave. 3.4, n=53); lateral margins straight to slightly concave or convex; distal margins straight or slightly convex, finely dentate with 2 to 14 teeth; teeth semicircular or obtusely rounded, separated by acute sinuses, 70μm to 0.5 mm long, 0.1 to 1.3 mm wide, L:W ratio 0.1 to 3.0 (ave. 0.8, n=37), becoming shorter and more alike in size in larger leaflets; midclefts (Fig. 4.3.1; Pl. 5, Fig. 2) prominent in broad leaflets, obtusely pointed, incised 0.2 to 1.6 mm deep, resulting symmetrical (occasionally assymetrical) lobes may be incised by shallower, obtusely pointed or rounded secondary clefts 0.3 to 0.6 mm deep; single vein divides shortly after entering base of individual

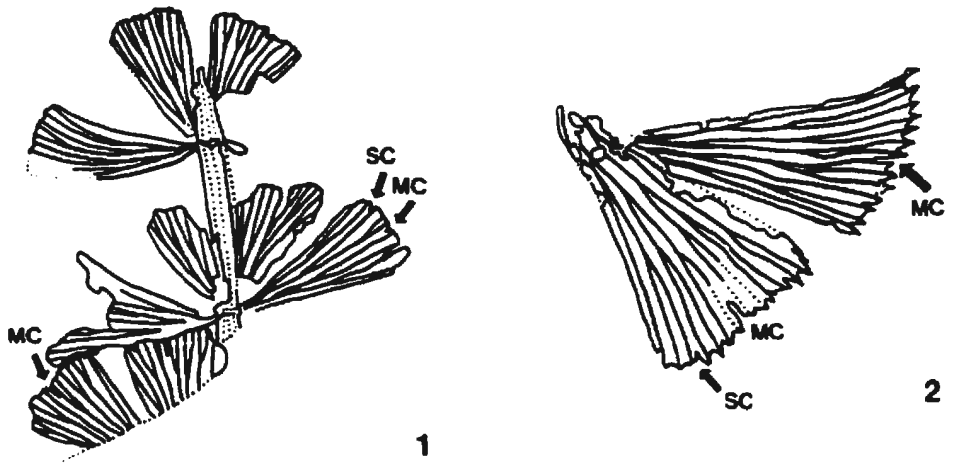


Figure 4.3. Schematic line drawings of sphenophyll leaflets. (1.) Broad leaflets of *Sphenophyllum emarginatum* incised by midcleft (MC) and secondary clefts (SC), with each vein ending at terminus of rounded tooth; BB-94-30-22, x2. (2.) Symmetrical (lower) and asymmetrical (upper) leaflets of *Sphenophyllum* sp. cf. *S. zwickaviense* incised by midcleft (MC) and secondary clefts (SC), with each vein terminating as sharp point of acute-triangular tooth; BB-96-30-73, x3.

leaflet, subsequently dichotomises 2-3 times with increasing distance between successive dichotomies, each branch terminates at distal end of single tooth (Fig. 4.3.1; Pl. 5, Fig. 2).

REMARKS – Although material recovered from Blanche Brook is morphologically diverse and represents at least 2 if not 3 orders of branching, much of it matches remarkably well with vegetative segments of the reconstruction of *S. emarginatum* established by Batenburg (1977). (i) Main axes recovered from Blanche Brook have dimensions comparable to his "main axes" and foliage most closely resembles his "first" and "second type" linear leaflets (see pl. 5, figs. 2, 4, p. 86, 87); in accordance with Batenburg's plant reconstruction (fig. 5, p. 91), main axis specimens in the BBA probably represent proximal portions of main axes of *S. emarginatum*; (ii) large branches of the BBA parallel Batenburg's "larger branches" and foliage most closely resembles

bipartite leaflets (pl. 6, figs. 1, 2, p. 88, 89) that he considers to belong to proximal portions of larger branches of *S. emarginatum*. Although not found in organic connection in the BBA, large branches almost certainly arise (singly?) from nodes of main axes; and (iii) twigs from the BBA are identical to "twigs" described by Batenburg (p. 87, 90), even with regard to the variability of shape and number of teeth (i.e., more teeth, more cuneiform) on leaflets (Pl. 4, Fig. 6) depending on the point of insertion on axes.

Some notable differences exist, however, between vegetative elements of *S. emarginatum* described in this study and previously published material. Batenburg (1977) was the first to describe perpendicular hairs up to 1 mm long arising from some axes, and considered that they were relatively common features. However only one twig axis from Blanche Brook exhibited such hairs (Pl. 5, Fig. 5). In contrast to Storch (1966), who stated that no known specimens of *S. emarginatum* bore more than a single branch at any given node, one specimen (Pl. 4, Fig. 8) clearly demonstrates two foliated twigs arising from the same node of a main axis. Similarly, Zodrow (1989, pl. 6, p. 324) shows this same feature, and Batenburg (1977, pl. 5, fig. 2) figured a main axis node bearing two young branches. Batenburg (1977) suggested that twigs were spirally (dextrorsally) arranged on larger branches, with a twig arising at every third node from one of three ribs on the axis (see his pl. 4, fig. 1, p. 84). However, this must not always be the case, as one specimen shows two twigs springing from adjacent nodes of a large branch (Pl. 4, Fig. 1). In addition, numerous authors described *S. emarginatum* as having whorls comprising six to nine cuneiform leaflets, but a whorl recovered from the BBA clearly contains ten (Pl. 4, Fig. 4).

Sphenophyllum sp. cf. *S. zwickaviense* Storch, 1966

Fig. 4.3.2 (p. 57); Pl. 6, Figs. 1 to 4

1966 *Sphenophyllum zwickaviense*, Storch, pp. 303-305; figs. 34, 35; pl. 23, fig. 4; pl. 24, figs. 1-4; pl. 25, figs. 1-6.

1977 *Sphenophyllum zwickaviense*, Batenburg, pp. 70-76; text-fig. 1 (p. 74); pl. 1, fig. 1-4.

1980 *Sphenophyllum zwickaviense*, Storch, pp. 181-183; pl. 8, fig. 2?

1986 *Sphenophyllum zwickaviense*, Zodrow, pp. 310-312; text-fig. 8 (p. 312); pl. 5.

1989a *Sphenophyllum zwickaviense*, Zodrow, pp. 318-322; text-figs. 10-12 (p. 318); table 3 (p. 304); table 4 (p. 322); pl. 1, fig. 6; pl. 5.

MATERIAL AND OCCURRENCE – Six isolated leaflet fragments from BB-30 preserved as "naturally macerated" volatilized adpressions (veins coalified).

DESCRIPTION – Leaflets cuneate, >9.4 to >13.9 mm long, >3.6 to 10.7 mm wide at distal margin (approximate measurements as full length and width? generally not preserved), L:W ratio >1.2; lateral margins straight; distal margins slightly convex, dentate with ca. 11 to 14 teeth; teeth acute-triangular, separated by obtusely pointed sinuses, 0.5 to 1.4 mm long, 0.5 to 0.8 mm wide, L:W ratio 1.0 to 2.2; midcleft incised >1.2 to ca. 2.9 mm resulting in two (often asymmetrical) lobes each with 4 to 7 teeth; secondary clefts incised >0.7 to ca. 1.1 mm into lobes; single vein divides shortly after entering base of leaflet, subsequently dichotomises 2 to 3 times with increasing distance

between successive dichotomies, each vein ca. 50 µm wide terminates as sharp point at distal end of single tooth (Fig. 4.3.2; Pl. 6, Fig. 1).

REMARKS – Although material is rather fragmentary, enough pertinent morphological information was obtained to tentatively refer the leaflets to *S. zwickaviense*. Some notable differences exist, however, between specimens from Blanche Brook and better preserved material described from Germany and Sydney Coalfield (Storch 1966, 1980; Batenburg 1977, 1981; Zodrow 1986, 1989a). In particular, leaflets of *S. zwickaviense* typically are divided into asymmetrical lobes by a main cleft that reaches 1/3 to 1/2 the length of the leaflet (Batenburg 1977). In contrast, rare leaflets from Blanche Brook are divided into symmetrical lobes by a relatively shallow midcleft (ca. 1/11 the length of leaflet) (Fig. 4.3.2; Pl. 6, Fig. 1), although abrasion of the distal end of the leaflet precludes accurate measurement.

S. zwickaviense can be distinguished from *S. emarginatum*, which is considerably more common at Blanche Brook and characterized by semi-circular or obtusely-rounded teeth, by having acute-triangular teeth and larger, (generally) asymmetrical leaflets that are incised by a deeper midcleft and secondary clefts (compare Figs. 4.3.1 and 4.3.2).

Order EQUISETALES

Form-genus *Annularia* Sternberg, 1821

Annularia sphenophylloides (Zenker) Gutbier, 1837

Pl. 6, Figs. 5, 7 to 10; Pl. 7, Fig. 1

1938 *Annularia sphenophylloides*, Bell, p. 84; pl. 85, fig. 3; pl. 87, fig. 1.

1958 *Annularia sphenophylloides*, Abbott, pp. 319-321; chart 2 (p. 307); pl. 35, fig. 6; pl. 41, fig. 55.

1962 *Annularia sphenophylloides*, Bell, p. 51; pl. 44, fig. 7.

1966 *Annularia sphenophylloides*, Bell, pl. 35, fig. 2.

1969 *Annularia sphenophylloides*, Crookall, pp. 733-739; text-fig. 215 (p. 737); pl. 149, fig. 1.

1969 *Annularia sphenophylloides*, Darrah, p. 172; pl. 33, figs. 1, 2; pl. 43, fig. 7.

1977 *Annularia sphenophylloides*, Remy and Remy, p. 372; fig. 227, a-d.

1991 *Annularia sphenophylloides*, Josten, pp. 78-80; text-fig. 36 (p. 79); table 4 (pp. 84-85); pl. 22, figs. 1, 1a, 2.

MATERIAL AND OCCURRENCE – Abundant isolated verticils with less common ultimate or penultimate axes from BB-30 preserved as (occasionally "naturally macerated") volatilized or decarbonized adpressions.

DESCRIPTION – Penultimate axes articulate, longitudinally striate, with verticils and oppositely paired, distichous ultimate branches borne from nodes, rarely with slightly curved, thin hairs 0.5 mm long,; ultimate axes articulate, faintly longitudinally striate, not exceeding 0.9 mm wide, thinning distally to ca. 0.1 mm, verticils borne from nodes; internodes 7.8 to 13.5 mm apart, regularly spaced but length decreases considerably near apices; verticils typically distant but contiguous or overlapping next higher verticil near apices of axes, markedly symmetrical, comprise 10 to 15 leaflets per whorl radiating from tiny sheath that encircles axis; sheath (Pl. 6, Fig. 7) inconspicuous, circular, usually

<0.5 mm but up to 1.9 mm in diameter; leaflets spatulate with broad mucronate tips (Pl. 6, Fig. 9) (often obtusely rounded because tip embedded in matrix), 2.4 to 7.4 mm long, 0.5 to 2.8 mm wide at widest point ca. 4/5 to 5/6 up leaflet, L:W ratio 2.4 to 6.7 (ave 4.0, n=111); lateral margins straight, approximately parallel to and distant, contiguous or overlapping adjacent leaflets; single midvein 0.1 to 0.4 mm wide (ave. 0.2 mm, n=41), occupies ca. 1/5 leaflet width, flares at distal margin (terminal expansion) before protruding as acuminate tip.

REMARKS – A few specimens in the BBA exhibit a terminal expansion of the midvein near the distal leaflet margin (Pl. 6, Fig. 7); this feature is well demonstrated by a transfer preparation of *A. sphenophylloides* figured by Crookall (1969, text-fig. 215, p. 737). His figure also shows hairs or hair bases on the leaflet, and Bell (1962, p. 51) suggested that specimens of *A. sphenophylloides* from Westphalian strata of New Brunswick had villous leaves with hairs mainly attached to midveins. In contrast, no hairs were observed on any leaflets studied herein, and Abbott (1958) found no evidence for such hairs.

The relatively large sheath size (up to 1.9 mm) on some whorls (Pl. 6, Fig. 10) does not conform to Abbott's (1958) criteria for *A. sphenophylloides* (sheath size 0.3 to 0.5 mm). Hence either the whorls may in fact be referable to *A. mucronata*, or the apparent disagreement may be related to taphonomic distortion.

Annularia stellata (Schlotheim) Wood, 1861

Pl. 7, Fig. 6

1938 *Annularia stellata* forma *mucronata*, Bell, p. 85; pl. 90, figs. 1,2.

1944 *Annularia stellata* forma *longifolia*, Bell, p. 102; pl. 70, fig. 5.

1958 *Annularia stellata*, Abbott, pp. 321-326; chart 2 (p. 307); pl. 35, fig. 1; pl. 41, fig. 58; pl. 49, fig. 87.

1966 *Annularia stellata*, Bell, pl. 28, fig. 6.

1969 *Annularia stellata*, Crookall, pp. 717-725; text-fig. 209 (p. 721); pl. 149, fig. 3.

1969 *Annularia stellata*, Darrah, p. 172; pl. 37, fig. 1.

1977 *Annularia stellata*, Remy and Remy, pp. 369-371; text-fig. 225a-c (p. 370).

1991 *Annularia stellata*, Josten, pp. 69-72; text-figs. 29, 30; table 4 (p. 84-85); pl. 15; pl. 16, figs. 1-3; pl. 17

MATERIAL AND OCCURRENCE – Part (devolatilized adpression) and counterpart (decarbonized adpression) of single very poorly preserved specimen from BB-30 comprising two whorls attached to axis.

DESCRIPTION – Axis articulate, ca. 2.0 mm wide, with obscure longitudinal ridges, bearing verticils from nodes ca. 21.0 mm apart; verticils asymmetrical, overlapping, decreasing in diameter distally, comprising 14 to 19 leaflets radiating from elliptical sheath ca. 1.6 x 2.1 mm in diameter; leaflets oblanceolate to spatulate-lanceolate, slightly arched or concavo-convex in cross section, apices obtusely rounded or subacutely to bluntly pointed with sharp mucronate tip, 1.9 to 3.2 mm wide at broadest point (ca. 1/2 to 3/5 up leaflet), 15.0 to 26.4 mm long (including distal spine like point up to 1.2 mm long), lateral leaflets lying approximately normal to axis conspicuously longer, L:W ratio

6.7 to 11.9 (ave. 8.8, n=10); single midvein 0.2 to 0.6 mm wide, occupying ca. 1/9 to 1/5 leaflet width, extrudes from apex as stiffened mucronate tip.

REMARKS – Although criteria of Abbott (1958) indicates that leaflets of *A. stellata* lack mucronate tips, which she suggests permits distinction from *A. mucronata*, the specimen from Blanche Brook clearly has leaflets with sharp, stiffened mucronate tips (Pl. 7, Fig. 6). Similarly, Bell (1938) described mucronate tips on leaflets of *A. stellata* forma *mucronata* from Sydney Coalfield. Thus both taxa probably have mucronate tips, although apices often appear obtusely rounded when tips are partially or completely concealed in the matrix as a result of inrolling of the laminae's outer margins. Accordingly, distinction between *A. stellata* and *A. mucronata* likely is more suitably based on leaflet size and shape [widest near middle and 14 to 75 mm long; widest near apex and 4 to 25 mm long, respectively – measurements from Abbott (1958)]. With these criteria, the specimen from Blanche Brook clearly is referable to *A. stellata*.

Although Bell (1938) apparently observed hairs measuring about 1 mm long arising from axes and adaxial leaflet surfaces of *A. stellata*, no hairs were observed in the specimen from Blanche Brook (although it is poorly preserved). Similarly, Abbott (1958) was unable to detect any hair on the lamina, axis or sheath.

Form-genus *Asterophyllites* Brongniart, 1822

***Asterophyllites equisetiformis* (Sternberg) Brongniart, 1828**

Pl. 7, Figs. 2, 4

1938 *Asterophyllites equisetiformis*, Bell, p. 86; pl. 87, figs. 3, 4; pl. 88, fig. 1.

1944 *Asterophyllites equisetiformis*, Bell, p. 103; pl. 70, fig. 2; pl. 71, fig. 3.

1958 *Asterophyllites equisetiformis*, Abbott, pp. 299-302; chart 1 (p. 297); pl. 35, fig. 4; pl. 39, figs. 46, 47, 49, 50.

1966 *Asterophyllites equisetiformis*, Bell, pl. 28, fig. 7; pl. 29, fig. 4; pl. 36, fig. 3.

1969 *Asterophyllites equisetiformis* forma *typica*, Crookall, pp. 695-700; text-fig. 203; pl. 142, fig. 3.

1969 *Asterophyllites equisetiformis*, Darrah, p. 173; pl. 40, figs. 3, 4.

1977 *Asterophyllites equisetiformis* var. *jongmansi*, Remy and Remy, p. 377; text-fig. 229a-c (p. 375).

1991 *Asterophyllites equisetiformis* forma *jongmansi*, Josten, pp. 89-91; text-fig. 43 (p. 90); table 5 (98-99); pl. 26; pl. 27.

MATERIAL AND OCCURRENCE – Two devolatilized adpression fragments from BB-30.

DESCRIPTION – Axes articulate, with distinct pattern of longitudinal grooves and ridges ca. 0.8 mm apart; internodes 0.4(?) to 1.3 mm wide, 1.7 to 6.2 mm long, dimensions decreasing distally; nodes swollen, 0.6(?) to 1.9 mm wide, bearing verticils; whorls comprise at least 12 leaflets of approximately equal length, decrease in diameter apically, overlap and crowd next higher verticil (particularly near apices of axes); leaflets fused by proximal ends into sheath cupped about axis, linear-lanceolate, with sharply pointed acuminate apices, parallel lateral margins, attached to axis at ca. 10 to 80°, extend straight

but curve upwards in apical verticils, ca. 10.8 mm long, 0.2 to 0.7 mm wide, L:W ratio ca. 21.0; single midvein ca. 0.13 mm wide, occupies ca. 1/5 leaflet width.

REMARKS – Leaflet dimensions are only approximate because part of the whorls and leaflets typically are embedded in the matrix. Two similar forms of *A. equisetiformis* that differ in width, length and arrangement of leaflets in a whorl were recognized by Jongmans and Kukuk (1913; cited in Crookall 1969). Based on comparisons with figured material and criteria outlined by Josten (1991, table 5, p. 98-99), material from Blanche Brook clearly belongs to var. *jongmansi* of Remy and Remy (1977) (= forma *typica* of Jongmans and Kukuk 1913).

cf. *Asterophyllites* sp.

Pl. 7, Figs. 3, 5, 9

MATERIAL AND OCCURRENCE – Five devolatilized adpressions from BB-19 with up to three orders of branching.

DESCRIPTION – Primary axes articulated, with longitudinal striae superimposed on ribs 0.4 mm apart, 0.7 to 1.9 mm wide, breadth decreasing distally; internodes 6.5 to >18.2 mm long; nodes slightly swollen, 1.0 to 1.6 mm wide, bearing distichous secondary axes and/or verticil of indeterminate number of leaflets that cup axis; leaflets stiff, stout, acuminate, with single nerve, 2.6 to 3.5 mm long, ca. 0.4 mm wide, broadest at base, proportionately shorter and thinner near apices; secondary axes articulate, with faint longitudinal striae, 0.4 to 0.8 mm wide; internodes 3.4 to 6.6 mm long, longest near

middle of axis; nodes slightly thickened, 0.4 to 0.6 mm wide, bearing distichous tertiary axes and/or indeterminate number of leaflets; leaflets 1.6 to 2.5 mm long, 0.2 to 0.4 mm wide; tertiary axes articulate, 0.2 to 0.4 mm wide, proportionately shorter and thinner in apical portions of secondary axes, culminate in bud like structure sitting atop short stalk; internodes 0.9 and 2.5 mm long, length decreasing distally; nodes unthickened, bearing verticils; whorls cup like around axis, generally distant but overlapping adjacent verticil near apices; leaflets linear, acuminate, 1.5 to 2.9 mm long, 0.2 to 0.4 mm wide; "bud" (Pl. 7, figs. 3, 5) oval to elliptical, enclosed by sterile bracts identical to those further down axis, 0.8 to 0.9 mm wide, 1.1 to 1.6 mm long.

REMARKS – The articulate axes, longitudinal ribbing, and whorls of thin leaflets arising from each node clearly indicates affinity of these specimens with the sphenopsid group. In particular, the fragments likely represent the distal portions of branching foliage that arose from a calamitean plant, and most closely resemble the linear leaflets of the form-genus *Asterophyllites*. This interpretation is supported by the association of *Calamites* sp. impression fragments in the assemblage at locality BB-19. Plant fragments resemble *Asterophyllites charaeformis* (see Bell 1940, pl. 10, fig. 3; Josten 1991, pl. 31, figs. 2, 2a) and *A. paleaceus* (Josten 1991, pl. 31, figs. 3, 3a), although apparently branches of these taxa simply end in subacuminate tips.

Calamites Suckow ex Brongniart, 1828

Calamites sp. A

Pl. 7, Fig. 8; Pl. 8, Fig. 3

MATERIAL AND OCCURRENCE – Single decarbonized adpression fragment BB-30.

DESCRIPTION – Axis cylindrical, articulate, longitudinally ribbed, 15.5 cm long, 6.7 cm wide; nodes at least 12.5 cm apart, with ribs alternate; ribs convex, with irregular longitudinal striae, separated by shallow furrows ca. 2.6 to 3.1 mm apart, terminate as obtusely rounded apices at nodes where alternate, apices occupied by oval to semicircular scars (infranodal canals; Pl. 7, Fig. 8) 0. 9 to 1.1 mm long and 0.4 to 0.8 mm wide.

REMARKS – The genus *Calamites* typically has ribs that alternate at nodes, and thus this specimen likely can be included in this taxon (Pl. 7, Fig. 8). However, small *Calamites* sp. stem fragments are nearly impossible to identify, particularly when only a small portion of the total axis and a single node are preserved, because species are differentiated based on a combination of internodal and nodal features (Crookall 1969).

Calamites sp. B

Pl. 7, Fig. 7; Pl. 8, Fig. 4

MATERIAL AND OCCURRENCE – Single axial fragment BB-25 preserved as devolatilized (part) and decarbonized adpression (counterpart).

DESCRIPTION – Axis cylindrical, articulate, longitudinally ribbed, 14.7 cm long, 5.4 cm wide; nodes slightly swollen, at least 12.4 cm apart; ribs moderately well defined, convex, with irregular longitudinal striae, separated by furrows ca. 0.7 to 1.0 mm apart, pass directly through nodes (i.e., not alternating).

REMARKS – In contrast to many species within the genus *Calamites*, this specimen has longitudinal ribs that pass directly through (Pl. 7, Fig. 7) rather than alternating at nodes (Crookall 1969).

Form-genus *Myriophyllites* Artis, 1825

cf. *Myriophyllites gracilis* Artis, 1825

Pl. 8, Figs. 1, 2

1969* *Myriophyllites gracilis*, Crookall, pp. 781-783; text-fig. 224 (p. 783); pl. 150, fig. 6.

1991* *Myriophyllites gracilis*, Josten, p. 109; pl. 37, fig. 1.

MATERIAL AND OCCURRENCE – Single specimen from BB-29 comprising at least three orders of branching; preserved as "naturally macerated" volatilized adpression, with conspicuous devolatilized (coalified) vascular strands.

DESCRIPTION – Main root axis branching irregularly (in several planes), divided longitudinally into rounded ridges and furrows, ca. 12.5 cm long, 8.0 mm wide, thinning distally to abrupt, obtusely rounded apex, covered with irregularly disposed rootlets (especially near apex); secondary root axes morphologically identical to main root, 5.5 mm wide; tertiary root axes 2.0 mm wide; rootlets linear, hair like, rarely branching (Pl. 8, Fig. 2), ca. 0.75 mm wide; vascular strands evident as longitudinal lines parallel to long axis of roots (Pl. 8, Fig. 2), ca. 0.3 mm wide, comprise entirety of rootlets.

REMARKS – *Myriophyllites gracilis* is the monotypic adpression form-genus of root structures that almost certainly belong to *Calamites* (Crookall 1969). Although there are no distinct differences between *Myriophyllites* and *Pinnularia*, the former subdivides much more irregularly in more than one plane and has definite longitudinal ribs that evince its affinities with *Calamites* (Crookall 1969).

Form-genus *Paracalamostachys* Weiss, 1884

***Paracalamostachys* sp. Weiss, 1884**

Pl. 8, Fig. 5

1969* *Calamostachys calathifera*, Crookall, pp. 756-757; pl. 109, fig. 7.

MATERIAL AND OCCURRENCE – Single slab from BB-30 containing devolatilized adpressions of nine nearly complete cones.

DESCRIPTION – Fructifications cylindrical, not exceeding 2.8 cm long, 4.7 to 6.1 mm broad, apices broadly rounded but slightly pointed; internodes <1.4 to 3.0 mm apart, decreasing in length distally, separated by nodes bearing verticils; whorls comprise sterile bracts, cup axis, slightly curved inward near tops, typically overlap bases of next higher verticil but completely enclose adjacent whorls near apices; bracts stiff, stout, acuminate, ca. 2.9 mm long, ca. 0.6 mm wide at base.

REMARKS – These fructifications are slightly smaller than but otherwise strongly resemble specimens of *Calamostachys calathifera* figured and described by Crookall (1969). However, because the cones are not well enough preserved to determine the

number and position of sporangiophore insertion between verticils, the cones are better referred to *Paracalamostachys* (see Good 1975 for criteria).

Sterzel (1882, cited in Crookall 1969) demonstrated that *C. calathifera* represents the fructification of a calamitean plant bearing *Annularia sphenophylloides* foliage. The abundance of *A. sphenophylloides* fragments together with the cones on a single slab (Pl. 8, Fig. 5) strongly suggests reference of the material to *C. calathifera*, and corroborates earlier evidence of whole plant affinities.

Form-genus *Pinnularia* Lindley and Hutton, 1834

***Pinnularia capillacea* Lindley and Hutton, 1834**

Pl. 6, Fig. 6

1969 *Pinnularia capillacea*, Crookall, pp. 778-780; text-fig. 223 (p. 779); pl. 109, fig. 8.

1978 *Pinnularia capillacea*, Boersma, p. 65; pl. 7, fig. 2.

1991 *Pinnularia capillacea*, Josten, p. 110; pl. 37, figs. 2, 2a, 3.

MATERIAL AND OCCURRENCE – Single slab from BB-30 containing devolatilized adpressions of two branching axes.

DESCRIPTION – Axes (secondary roots?) slender, ca. 1.0 mm wide, lacking nodes, with faint longitudinal striae, bearing rootlets in single plane at fairly regular intervals ca. 4.0 to 6.0 mm apart; rootlets linear, narrow, ca. 0.5 mm wide.

REMARKS – Although *Pinnularia* is often thought of as the form-genus of *Calamites* sp. root structures, the organs likely belonged to a variety of unrelated plants (Crookall 1969; Darrah 1969). These specimens probably represent distal portions of secondary roots bearing capillary rootlets.

4.3 Division PTERIDOPHYTA

Order FILICALES

Pecopteris (Brongniart) Brongniart, 1828

Pecopteris plumosa (Artis) Brongniart, 1832

Fig. 4.5.5 (p. 82); Pl. 15, Figs. 1 to 4; Pl. 16, Figs. 1, 2, 4, 5, 7

1938 *Dactylotheca plumosa* forma *dentata*, Bell, pp. 76-77; pl. 73, fig. 3; pl. 77, figs. 3, 4(?); pl. 80, fig. 1.

1944* *Pecopteris (Senftenbergia) plumosa* forma *crenata*, Bell, pp. 84-85; pl. 38, figs. 1-4; pl. 39, figs. 5, 6.

1951 *Pecopteris (Senftenbergia) plumosa-dentata*, Corsin, pp. 199-208; text-fig. 42a-c (p. 201); pl. 112, figs. 1-3; pl. 113, fig. 2; pl. 114, figs. 1-4; pl. 115, figs. 1-4; pl. 116; pl. 117, figs. 1-3a; pl. 118, fig. 2.

1951 *Pecopteris Bioti*, Corsin, pp. 208-210; text-fig. 43 (p. 209); pl. 196, figs. 2, 2a.

1960 *Pecopteris (Senftenbergia) plumosa-dentata*, Dalinval, pp. 51-82; text-fig. 7a, b (p. 56); text-fig. 9(?) (p. 70); text-fig. 10 (p. 73); text-fig. 11 (p. 77); pl. 5, figs. 1-3; pl. 6, figs. 1-2a; pl. 7, figs. 2, 2a; pl. 8, figs. 1-3a; pl. 9, figs. 1-2a; pl. 10, figs. 1, 1a; pl. 13, figs. 1-1c; pl. 14, fig. 1.

1960 *Pecopteris plumosa-dentata* forma *Bioti*, Dalinval, p. 72; text-fig. 10, p. 73; pl. 10, fig. 1a; pl. 15, figs. 3, 3a.

1966* *Senftenbergia plumosa*, Bell, pl. 5, fig. 18.

1969 *Pecopteris plumosa*, Darrah, pp. 127-128; pl. 13, fig. 4.

1977 *Pecopteris plumosa*, Remy and Remy, pp. 232-233; text-fig. 116a, b (p. 232).

1991 *Pecopteris (Senftenbergia) plumosa*, Josten, pp. 283-284; text-figs. 180a, b & 181a, b (p. 283); table 19 (p. 289); pl. 151, figs. 1, 1a; pl. 152, figs. 1-2a.

MATERIAL AND OCCURRENCE – Numerous specimens from BB-30 comprising devolatilized and "naturally macerated" volatilized adpressions of ultimate and penultimate pinnae, and an antepenultimate pinna.

DESCRIPTION – Antepenultimate rachis (Pl. 15, Fig. 4) faintly striate, ca. 3.2 mm wide, with irregularly spaced punctae 228 to 269 μm in diameter; racheis of penultimate pinnae often curved apically, slightly flexuous, smooth or with irregular longitudinal striae, usually with punctae 47 to 228 μm in diameter, up to 2.2 mm wide at base; penultimate pinnae (Pl. 15, Figs. 1 to 4; Pl. 16, Figs. 1, 2, 4, 5, 7) alternate, arise obliquely at 35 to 45°, decurrent, linear-lanceolate to elongate-triangular, up to 16.4 cm long, 7.2 cm wide, broadest point between base and 1/4 up pinna; lateral margins straight to somewhat concave, gradually converge from widest point to acutely rounded, lobate apex.

Racheis of ultimate pinnae prominent, longitudinally striate, 0.1 to 0.6 mm wide at base, extend directly to apex or bifurcate just beforehand; ultimate pinnae opposite, sub-opposite or alternate, arise obliquely at 50 to 90° (angle increasing proximally),

slightly overlapping to distant, linear-lanceolate, straight to gently curved, of various dimensions depending on insertion point on frond; lateral margins either gradually converge or remain essentially parallel to 1/2 or 2/3 up pinna before gradually converging to summit; apex subtriangular to elongate-triangular, acutely to broadly rounded, lobate; *distal ultimate pinnae* (Fig. 4.4.E; Pl. 15, Figs. 1 to 3) 6.0 to 13.9 mm long, 2.2 to 5.0 mm wide, broadest at base; *proximal ultimate pinnae with entire pinnules* (Fig. 4.4.F; Pl. 15, Figs. 1, 3, 4; Pl. 16, Figs. 1, 2, 4, 5, 7) 10.9 to 38.8 mm long, 3.8 to 7.8 mm wide, broadest near middle; *proximal ultimate pinnae with pinnatifid pinnules* (Fig. 4.4.G; Pl. 15, Fig. 1) up to 60 mm long, ca. 14.9 mm wide, broadest in lower half.

Pinnules alternate, arise oblique to rachis at 45 to 75° (ave. 60 to 70°), adjoin rachis with entirety of base, contiguous or united with bases of adjacent pinnules, subtriangular or linguaeform, semicircular when small (Pl. 15, Figs. 1, 2; Pl. 16, Fig. 4), subfalcate and curved apically with increasing size (Pl. 15, Fig. 1; Pl. 16, Fig. 1), apices narrowly or broadly rounded and somewhat pointed, laminae thin, of various dimensions depending on insertion point on frond; lateral margins curved (often convex), entire or pinnatifid; *entire pinnules of ultimate pinnae* (Fig. 4.4.E, F) 0.9 to 5.7 mm long, 0.8 to 2.9 mm wide, L:W ratio 1.12 to 2.38; *entire pinnules near apices of penultimate pinnae* (Fig. 4.4.H; Pl. 15, Figs. 2, 3) ca. 5.8 mm long, 2.8 mm wide, L:W ratio ca. 2.07; *pinnatifid pinnules on proximal ultimate pinnae* (Fig. 4.4.G; Pl. 15, Fig. 1) *or near apices of penultimate pinnae* (Fig. 4.4.J; Pl. 15, Figs. 2, 3) 4.2 to 9.4 mm long, 1.7 to 3.4 mm wide, L:W ratio 1.67 to 2.76, lobes 0.8 to 1.5 mm apart.

Midveins prominent, abrupt to markedly decurrent (Pl. 15, Fig. 1), slightly fasciculate, typically flexuous but straight in larger pinnules, 106 to 312 µm wide at base, extend directly to apex or bifurcate just beforehand; lateral veins (Fig. 4.5.5; Pl. 16, Figs. 2, 5, 7) prominent, arise at open angle (40 to 75°, ave. 45 to 55°), 28 to 103 µm wide, may be somewhat flexuous, extend nearly straight or arch gently to reach lateral margin at 45 to 90°, unbranched in small pinnules, with increasing development dichotomize once at open angle (ca. 20°) 1/3 to 1/2 way between midvein and lateral margin (Fig. 4.5.5).

REMARKS – Much of the material in the BBA especially resembles *Pecopteris plumosa-dentata* forma *Bioti* of Dalinval (1960), which is synonymous with *Pecopteris Bioti* of Corsin (1951). This variety has relatively small, subtriangular to linguaeform pinnules that have more broadly rounded (but often still slightly pointed) apices in comparison with other forms of the species. *P. plumosa* is rather easily distinguished from other pecopteroids in the BBA by the subtriangular and often subfalcate habit of its pinnules. The taxon could, however, be mistaken for *Pecopteris pennaeformis* – a case in point is a specimen identified as *P. (Senftenbergia) pennaeformis* by Bell (1962, pl. 26, fig. 2) that more closely resembles forma *bioti* of *P. plumosa*. However, pinnules of *P. pennaeformis* lack a subtriangular habit, are inserted perpendicular to the rachis, and have more prominent and less flexuous veins that generally dichotomize more than once (Dalinval 1960).

Although *P. plumosa* has conventionally been included in the form-genus *Pecopteris* (Order Marattiales), the taxon is generally regarded as a member of the extinct

family Tedeleaceae (Order Filicales) because its sporangia (*Senftenbergia*) are very similar to sporangia of the Tedeleacean *Ankyropteris* (Jennings and Eggert 1977; Mickle 1980).

Order MARATTIALES

Form-genus *Aphlebia* Presl, 1838

Aphlebia sp.

Pl. 9, Fig. 8

MATERIAL AND OCCURRENCE – Two pinnatifid pinnae fragments from BB-30 preserved as devolatilized adpression and "naturally macerated" volatilized adpression (with coalified veins).

DESCRIPTION – Pinnae membranous, elongate-triangular, incised to form lobes, dissection decreasingly deep distally, apex acute, not exceeding 29.5 mm long, 11.1 to 18.5 mm wide; rachis prominent, straight to gently flexuous, ca. 0.4 to 0.5 mm wide, broadly winged by laminae ca. 1.9 to 3.4 mm wide; lobes membranous, elongate-triangular, arise alternately and decurrently at ca. 30 to 50°, shallowly incised resulting in secondary lobes, 5.1 to 11.2 mm long, 1.3 to 6.5 mm wide; secondary lobes acutely triangular, better developed on proximal lobes; midveins extend entire length of lobe, ca. 0.2 mm wide near base; lateral veins unbranched, arise alternately and obliquely from midvein at ca. 20 to 25°, extend straight or curve slightly before terminating at distal end of secondary lobe.

REMARKS – This material is morphologically similar to *A. goldenbergi*, a species with a prominent, branching midvein (see Crookall 1976, text-fig. 248, p. 860; pl. 158, fig. 3). The form-genus *Aphlebia* is poorly defined and includes anomalous or modified foliage that grew near the base of primary pinnae of *Pecopteris* and *Sphenopteris* fronds (Crookall 1976). Unfortunately, the specific parent plant of most morphological species of *Aphlebia* is equivocal (Darrah 1969).

Form-genus *Lobatopteris* Wagner, 1958

***Lobatopteris* sp. A**

Figs. 4.5.1 to 4.5.3 (p. 82); Pl. 9, Figs. 1 to 7; Pl. 10; Pl. 11, Figs. 1 to 5; Pl. 12, Figs. 1 to 5; Pl. 13, Figs. 1 to 4; Pl. 14, Figs. 1 to 10

MATERIAL AND OCCURRENCE – Abundance of specimens from BB-30 and BB-32 comprising penultimate and ultimate pinnae preserved as devolatilized, decarbonized and "naturally macerated" (occasionally partially pyritized) volatilized adpressions. Cuticles fragmentary and poorly preserved.

DESCRIPTION – Exceedingly polymorphous leaves, with various forms of foliage depending on point of insertion on original frond. To simplify description, material has been separated into "distal elements" (i.e., positioned near apices of frond or branch) and "proximal elements" (i.e., positioned in interior of frond or branch). Figure 4.4 demonstrates assumed positions of frond fragments described in text. Expectedly, gradation exists between distal and proximal foliar end members.

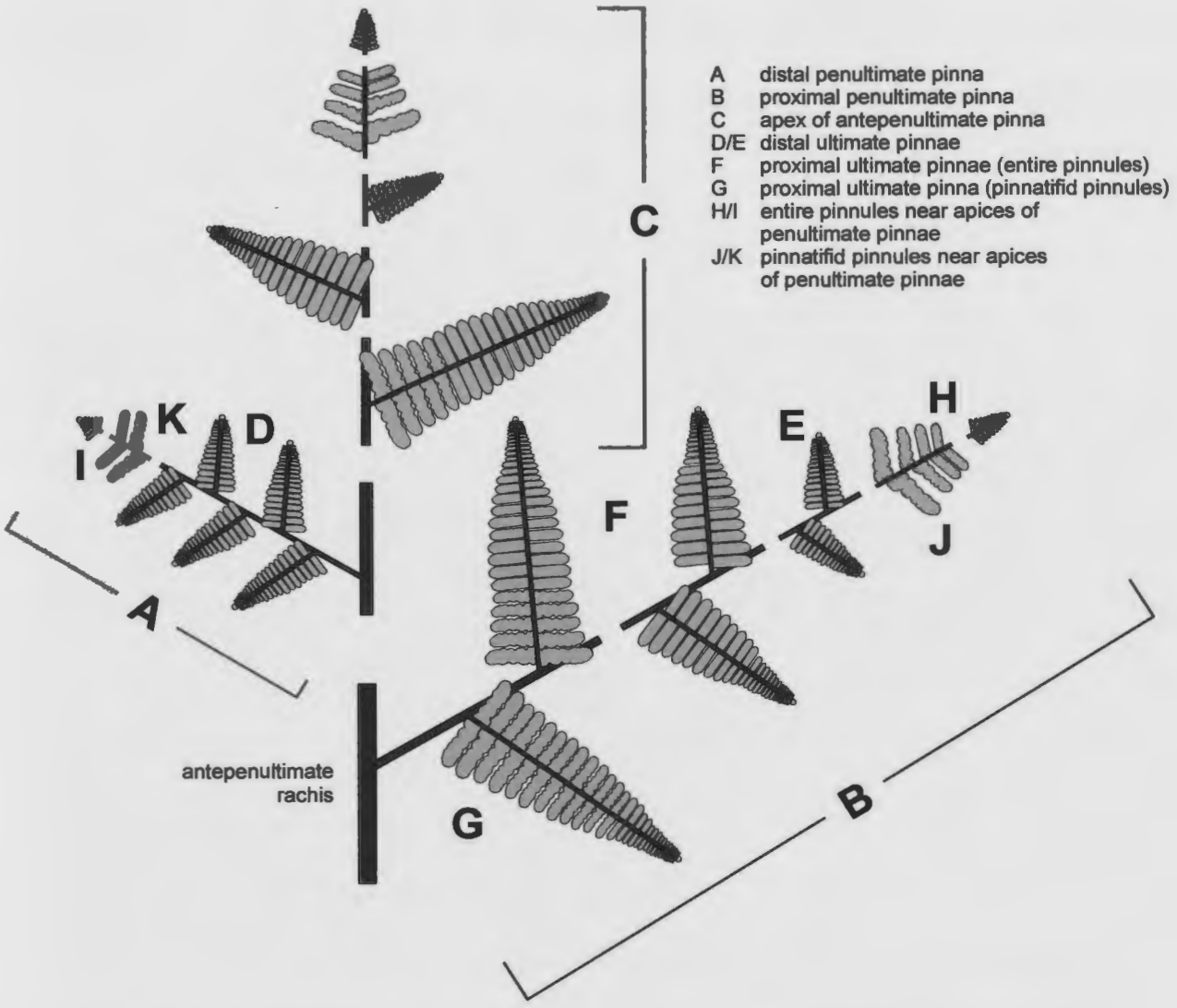


Figure 4.4. Schematic reconstruction of the architecture of a hypothetical antepenultimate pinna and constituent floral elements, showing definitions of elements as used in descriptions in the text of both marattialean tree fern and pteridosperm foliage.

Racheis of penultimate pinnae ribbed to longitudinally striate, occasionally punctate (Pl. 12, Fig. 3) but rarely with attached hairs, 2.4 to 5.6 mm wide, thinning distally to 0.7 mm wide; hairs linear, acuminate, 0.1 mm wide at base, not exceeding 1.7 mm long; *distal penultimate pinnae* (Fig. 4.4.A; Pl. 9, Figs. 1, 2, 5, 7; Pl. 11, Figs. 1, 3, 4) linear-lanceolate(?), slightly overlapping to distant, not exceeding 7.8 cm long or 6.5 cm wide, widest at or below midpoint; lateral margins straight, more or less parallel throughout much of length, converging very abruptly close to summit to form acutely rounded (Pl. 11, Fig. 3, 4) to subtriangular blunt apex (Pl. 9, Fig. 7); *proximal penultimate pinnae* (Fig. 4.4.B, C?; Pl. 10; Pl. 12, Figs. 1 to 3; Pl. 13, Fig. 1; Pl. 14, Fig. 4) elongate-triangular, up to 34.5 cm long and 20.5 cm wide; lateral margins straight to slightly concave, converging rapidly to form narrowly rounded, sub-triangular, lobate apex 1.3 mm long and 1.7 mm wide.

Racheis of ultimate pinnae arise abruptly to decurrently (particularly in distal pinnae; Fig. 4.4.D, E; Pl. 9, Fig. 7), straight to slightly flexuous, repressed but prominent, fasciculate to longitudinally striated, may be punctate with attached hairs, 0.1 to 2.0 mm wide near base, extend either directly to summit or bifurcate just beforehand; punctae ca. 75 μm diameter; hairs (Pl. 12, Fig. 4) linear, sharply acuminate, up to 0.6 mm long, 56 to 100 μm wide at base; ultimate pinnae linear-lanceolate, straight to gently curved, usually alternate but infrequently sub-opposite in distal positions, arise obliquely at 45 to 80° (ave. ca. 70°, angle decreasing distally), may overlap rachis with part of base, distant, contiguous or overlapping adjacent pinnae (increasingly distant proximally, Fig. 4.4.F), morphologies and dimensions differing considerably depending on insertion point on

frond; *distal ultimate pinnae* (Fig. 4.4.D, E; Pl. 9, Figs. 1 to 5, 7; Pl. 10; Pl. 11, Figs. 1, 3, 4) 7.6 to 34 mm long, 4.0 to 8.5 mm wide, broadest at base or at 1/2 to 2/3 up pinna; lateral margins either gradually converge throughout length, or parallel or diverge gradually to widest point before converging abruptly to summit; apex lobate, subtriangular to blunt or truncate, narrowly or obtusely rounded, ca. 0.8 to 1.2 mm long, 2.0 to 2.4 mm wide; *proximal ultimate pinnae comprising entire pinnules* (Fig. 4.4.F; Pl. 10; Pl. 11, Fig. 2; Pl. 12, Figs. 1, 2, 4, 5; Pl. 13, Figs. 1, 3; Pl. 14, Fig. 4), 21.0 to 123.0 mm long, 7.0 to 25.9 mm wide; lateral margins uneven or parallel for ca. 1/2 to 2/3 up pinna before gradually converging to summit; apex obtusely or narrowly rounded, subtriangular, lobate, may culminate as tiny, elliptical apical pinnule ca. 1.9 mm long and 3.1 mm wide; *proximal ultimate pinnae comprising pinnatifid pinnules* (Fig. 4.4.G; Pl. 9, Fig. 6; Pl. 10; Pl. 11, Fig. 5; Pl. 12, Fig. 3; Pl. 13, Figs. 2, 4; Pl. 14, Fig. 4) 120.0 to 127.3 mm long, 26.6 to 33.8 mm wide, broadest at ca. 1/2 to 2/3 up pinna; lateral margins straight, diverge gradually to widest point before constricting abruptly at summit; apex obtusely to broadly rounded, somewhat truncate, lobate.

Pinnules alternate, markedly decurrent, particularly when small (Pl. 9, Fig. 1 to 4; Pl. 12, Fig. 2, 4), arise oblique (rarely normal) to axis at 35 to 90° (ave. ca. 55 to 70°, angle increasing proximally), broadly attached by basiscopic side, acroscopic side may be slightly incised (Pl. 9, Figs. 3, 6; Pl. 11, Figs. 2, 3; Pl. 13, Fig. 3), may be confluent with base of adjacent pinnules, distant, contiguous or overlapping, adaxial surfaces frequently with scaly to roughened texture because covered by dense mass of tiny hairs that conceal venation, abaxial surfaces rarely with sori that obscure venation, pinnule morphologies

and dimensions differing considerably depending on insertion point on frond; *pinnules of distal ultimate pinnae* (Fig. 4.4.D, E; Pl. 9, Figs. 1 to 5, 7; Pl. 11, Figs. 1, 3, 4) subrectangular to linguaeform, semicircular when very small, asymmetrical and curved (because strongly decurrent), apices broadly rounded, 1.3 to 4.6 mm long, 1.0 to 2.5 mm wide, generally broadest near middle, L:W ratio 1.12 to 2.56; *pinnules of proximal ultimate pinnae* (Fig. 4.4.F, G) linguaeform or less commonly linear (Pl. 13, Figs. 3, 4; Pl. 14, Fig. 4), broadly to acutely rounded apex, straight to slightly curved, infrequently with thin compression margin ca. 103 to 122 µm wide; lateral margins entire to pinnatifid; *pinnules with entire margins* (Fig. 4.4.F; Pl. 10; Pl. 11, Fig. 2; Pl. 12, Figs. 1, 2, 4; Pl. 13, Figs. 1, 3) 2.1 to 12.2 mm long, 1.4 to 3.8 mm wide, L:W ratio 1.24 to 5.54; *pinnules with pinnatifid margins* (Fig. 4.4.G; Pl. 9, Fig. 6; Pl. 10; Pl. 11, Fig. 5; Pl. 12, Fig. 3; Pl. 13, Figs. 2, 4; Pl. 14, Fig. 4) 6.4 to 17.7 mm long, 3.0 to 5.7 mm wide, L:W ratio 1.80 to 5.23, lobes ca. 0.8 to 2.1 mm apart; *entire pinnules near apices of penultimate pinnae* (Fig. 4.4.H, I; Pl. 9, Fig. 7; Pl. 11, Figs. 3, 4) linguaeform, broadly rounded apex, straight to slightly curved, 1.9 to 10.6 mm long, 1.3 to 3.8 mm wide, L:W ratio 1.17 to 2.79; *pinnatifid pinnules near apices of penultimate pinnae* (Fig. 4.4.J, K; Pl. 9, Fig. 7; Pl. 11, Fig. 1, 3, 4) elongate-linguaeform, 5.8 to 15.1 mm long, 3.0 to 5.2 mm wide, L:W ratio 1.74 to 3.52, lobes 0.8 to 2.1 mm apart.

Midveins markedly decurrent (Pl. 9, Figs. 1 to 4; Pl. 12, Fig. 2, 4), may preferentially occupy basiscopic side of pinnule, curved to straight, bifurcate very near summit, often fasciculate, occasionally punctate with attached hairs, 88 to 760 µm wide at base; hairs (Pl. 12, Fig. 4) linear, acuminate, straight to curved, up to 2.9 mm long, 50

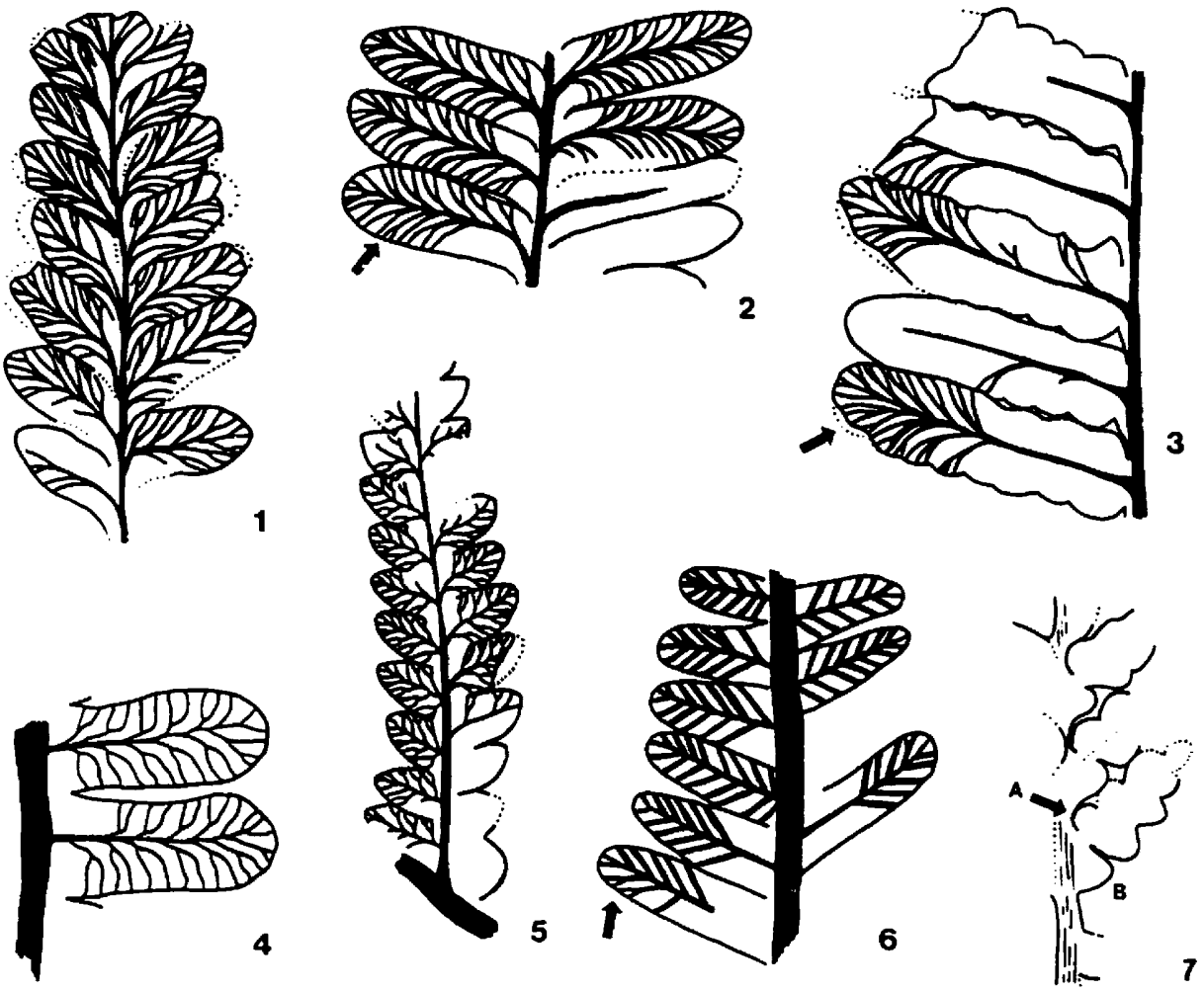


Figure 4.5. Schematic line drawings showing pinnule morphology and venation of ferns in BBA. (1.) Small pinnules of *Lobatopteris* sp. A; lateral veins either unbranched or dichotomize once with increasing size; BB-97-30-253, x3. (2.) Large, entire pinnules of *Lobatopteris* sp. A; lateral veins either once-dichotomized or, with increasing pinnule size, forming three-fold venation pattern (arrow) characteristic of form-genus; BB-96-30-170, x3. (3.) Increasingly developed venation (arrow) in pinnatifid pinnules of *Lobatopteris* sp. A (cf. Fig. 2); BB-97-30-245, x3. (4.) *Pecopteris* sp. cf. *P. herdii* pinnules with confluent bases; BB-97-30-247, x5. (5.) Ultimate pinna of *Pecopteris plumosa*; veins either unbranched or dichotomize once with increasing pinnule size; BB-97-30-239, x3. (6.) Pinnules of *Pecopteris* sp. cf. *P. cyathea*, with lateral veins generally unbranched but erratically dichotomizing (arrow); BB-96-30-129, x3. (7.) Penultimate pinna of pteridosperm(?) affinity, with ultimate pinnae adjoining striate rachis with basiscopic side (B) of base, while acroscopic side free (arrow); BB-96-30-126, x2.

to 94 µm wide at base; lateral veins curved, 28 to 212 µm wide, arise at 15 to 50° (ave. ca. 25 to 35°), arch to reach lateral margin at 35 to 90°, nearly straight and unbranched in small pinnules, increasingly arched and with characteristic pattern of bifurcation with increasing pinnule size (Figs. 4.5.1 to 4.5.3).

Sori (Pl. 14, Figs. 1 to 3) situated ca. 1/2 way between midvein and lateral margin, equally spaced along pinnule length, ca. 1.0 to 1.1 mm in diameter, comprising four sporangia; sporangia arranged in star, ovate to tear drop shaped, 0.48 to 0.65 mm long, 0.35 to 0.78 mm wide. Spores (Pl. 14, Figs. 5 to 10) circular to elliptical, monolete with inconspicuous laesurae, laevigate, thin walled but often with part of exine of distal surface markedly thickened, 22 to 40 µm long (diameter or long dimension; ave. 28 µm, $n = 14$).

REMARKS – Although distal and proximal elements of this rather polymorphous taxon typically are found separately, a large penultimate pinna frond (Pl. 10) demonstrates morphological gradation between distal and proximal portions of the original frond, and justifies the interpretation that the elements once were in organic connection. It is worth noting that although no complete antepenultimate pinnae were recovered, many of the frond fragments described herein may represent smaller portions of antepenultimate pinnae.

Material has tentatively been referred to the form-genus *Lobatopteris*, which Wagner (1958) defined for pecopteroid foliage of Corsin's (1951) *Pecopteris miltoni* Group. Pinnules within this group are characterized by a habit of gradual lobing (i.e.,

becoming increasingly pinnatifid), a diagnostic venation scheme, and the presence of *Asterotheca*-type fructifications.

Distal elements described from Blanche Brook are fully in accord with the "lobed fragments" of Wagner (1958), which comprise small, laterally fused pinnules with decurrent midveins and curved lateral veins that either are simple or bifurcate once. Similarly, proximal elements compare very closely with Wagner's (1958) "well developed or 'normal' pinnules", which are broadly attached, have perpendicular or only slightly decurrent midveins, and are linear or subtriangular in shape with broadly or obtusely rounded tops. Venation in these better developed fragments "... in its most simple form consists of only once bifurcated nervules, of which the upper branch dichotomizes mostly as well, so as to provide a characteristically threefold nervation. Afterwards, the middle branch of each nervurary group dichotomizes, which example is then followed by the lower and upper branches..." (Wagner 1958, p. 22; see also fig. 2, p. 10). Venation schemes in material from Blanche Brook conform fully with this diagnosis for *Lobatopteris* (see Figs. 4.5.1 to 4.5.3).

Two specimens of *Lobatopteris*, sp. A (Pl. 14, Figs. 1 to 3) possess star shaped fructifications that closely resemble *Asterotheca*-type sori [see Dalinval (1960), pl. 40, figs. 2a, 3a; =(?) *Cyathocarpus* of Mosbrugger (1983)], which lends further support to inclusion of the foliage in the form-genus *Lobatopteris*.

According to J.-P. Laveine (1969, 1970, personal communication Oct. 1998), the laevigate, monolete spores recovered from three sori closely resemble *Torispora*-type miospores that have previously been isolated from several different pecopterid species.

Those spores characterized by having a thickened exine on the distal surface (*Torispora* or *Crassosporites* configurations) (Pl. 14, Figs. 6, 7, 10) apparently matured near the periphery of the mass of spores within the sporangia, while unornamented spores devoid of this thickening (*Laevigatosporites*) (Pl. 14, Figs. 5, 8, 9) evidently resided near the centre of the mass of spores (Laveine 1969, 1970).

Distal frond elements from the BBA closely resemble what Corsin (1951) and Dalinval (1960) referred to as *Pecopteris miltoni* [=*Lobatopteris miltoni* of Wagner (1958); see especially Corsin (1951), pl. 154, figs. 2-3a; pl. 155, fig. 2; Dalinval (1960), pl. 33, fig. 1; pl. 34, figs. 1a, 3a; pl. 36, figs. 1-4a; pl. 40, fig. 1]. Nevertheless, C. J. Cleal (personal communication, Feb. 1999) cautions that Corsin's material is misidentified (*L. miltoni* does not actually occur in the central European intramontane basins!), while Dalinval may have included more than one species in his description of *L. miltoni*. The holotype of this taxon, an antepenultimate pinna, was recently redescribed and figured by Shute and Cleal (1989; pl. 1), and pinnatifid pinnules (or distal ultimate pinnae?) of the type specimen strongly resemble distal elements from Blanche Brook.

Proximal frond elements from Blanche Brook do not compare as closely to equivalent pinnae fragments of *L. miltoni* illustrated by Dalinval (1960; pl. 34, fig. 2; pl. 35, figs. 2, 2a; pl. 37, figs. 2, 2a; pl. 39, fig. 1, 1a), although this dissimilarity is to be expected if much of Dalinval's material was misidentified. Likewise, proximal pinnae on the holotype [see Shute and Cleal (1989); pl. 1; pl. 3, fig. 1] only partially resemble proximal elements from the BBA, although the type specimen "...is not entirely representative of the species and does not reflect the range of variation" (C. J. Cleal,

personal communication, Feb. 1999). Several of the proximal ultimate pinnae look similar to material from New Brunswick that Bell (1962, p. 30) assigned to *Pecopteris (Asterotheca) acadica* Bell (see Bell 1966, pl. 21, fig. 4). Zodrow and McCandlish (1980, p. 59) considered *P. acadica* to be synonymous with *Asterotheca miltoni*, although *P. acadica* is now thought to be a later synonym of *L. camertonensis* rather than *L. miltoni* (C. J. Cleal, personal communication, Feb. 1999). Some pinnae also compare closely with specimens figured by Bell (1938, especially pl. 68) from Sydney Coalfield as *Asterotheca miltoni* forma *abbreviata*, which he noted had more elongate pinnules than typical of *A. miltoni*.

Despite the obvious difficulties in distinguishing between members of Corsin's (1951) *P. miltoni* Group, combined with a lack of reliable published documentation of the group, it is concluded that the material described herein compares most closely with *L. miltoni*. This species can be distinguished from similar taxa, such as *Pecopteris bourozii* Dalinval, *Pecopteris lobulata* Dalinval and *Lobatopteris camertonensis* (Kidston) Wagner, by having proximal penultimate and ultimate pinnae with markedly more blunt apices, and more robust pinnules with conspicuous epidermal hairs and strongly decurrent midveins (Dalinval 1960; Shute and Cleal 1989; C. J. Cleal, personal communication, Feb. 1999).

Pecopteris (Brongniart) Brongniart, 1828

Pecopteris sp. cf. *P. cyathea* (Schlotheim)

Fig. 4.5.6 (p. 82); Pl. 17, Figs. 1 to 3

1938* *Eupecopteris (Asterotheca) cyathea*, Bell, p. 75; pl. 76, fig. 2.

1951* *Pecopteris cyathea*, Corsin, pp. 330-333; text-fig. 87b (p. 331); pl. 174, figs. 2-3; pl. 175, figs. 1, 2, 2a; pl. 176, figs. 1-1b; pl. 177, fig. 1.

1977 *Asterotheca* (al. *Pecopteris*) *cyathea*, Remy and Remy, p. 235; text-fig. 120a, b (p. 236).

1990 *Pecopteris cyathea*, Zodrow, pp. 25-34; text-fig. 13 (p. 27); text-fig. 14a (p. 28); pl. 1, fig. 1; pl. pl. 2., fig. 3?; pl. 5, fig. 1; pl. 6, figs. 1, 2; pl. 7, figs. 1, 2; pl. 8, fig. 3.

MATERIAL AND OCCURRENCE – Two ultimate pinnae from BB-30 preserved as devolatilized and "naturally macerated" volatilized adpressions.

DESCRIPTION – Racheis of ultimate pinnae repressed, ribbed or longitudinally striate, irregularly punctate, 1.1 to 1.2 mm wide at base; ultimate pinnae linear-lanceolate, up to 77 mm long, 14.7 to 18.3 mm wide; lateral margins parallel to 2/3 up pinna, then converge gradually before constricting abruptly to wide but acutely rounded apex; pinnules alternate, adjoin rachis with entirety of base, arise obliquely at 65 to 85° (to 50° near apices), slightly distant to slightly overlapping, elongate, oblong to linguaeform, obtusely rounded apices, 3.8 to 8.9 mm long, 2.2 to 3.2 mm wide, L:W ratio 1.73 to 3.18; lateral margins parallel, straight, entire; midveins very prominent, arise abruptly, 0.3 to 0.5 mm wide near base, extend straight directly to summit or divide just beforehand; lateral veins very prominent, widely spaced, arise at 40 to 50°, 166 to 300 μm wide, extend straight or barely curving to reach lateral margin at 45 to 60°, typically simple,

may fork once (erratically) near midvein (Fig. 4.5.6); sporangia (Pl. 17, Fig. 2) may occupy abaxial surface, ca. 0.7 mm long, 0.6 mm wide, arrangement indeterminate.

REMARKS – Specimens share several morphological features with members of the *Pecopteris arborescens* Group recently revised by Zodrow (1990). These include slightly inclined, distant pinnules with entire, parallel lateral margins; strictly nondecurrent, straight midveins that extend to or branch just prior to reaching the pinnule apex; and straight or slightly inclined lateral veins that are simple or bifurcate once. Although pecopterid fragments are notoriously difficult to determine, the material most closely resembles *P. cyathea*, a taxon characterized by relatively large pinnules with a combination of irregularly distributed simple and once-bifurcated lateral veins [Zodrow (1990), table 3, p. 11].

Although pinnule profiles of *P.* sp. cf. *P. cyathea* are nearly identical to pinnules borne on proximal ultimate pinnae of *Lobatopteris* sp. A, the former can be distinguished based on the strictly non-decurrent, straight midveins and comparatively prominent, straight and generally unbranched habit of the lateral veins (compare Fig. 4.5.6 with Figs. 4.5.1 to 4.5.3).

Pecopteris sp. cf. *P. herdii* Bell, 1938

Fig. 4.5.4 (p. 82); Pl. 17, Figs. 4 to 6, 9

1938* *Asterotheca herdi*, Bell, pp. 72-74; pl. 70, figs. 2, 4, 5; pl. 71, figs. 2, 4.

1980* *Asterotheca herdi*, Zodrow and McCandlish, p. 57; pl. 69, fig. 1.

1982 *Pecopteris herdii*, Gastaldo and Zodrow, p. 196; text-fig. 3h (p. 195).

1986* *Pecopteris herdii*, Zodrow and Vasey, p. 221; text-figs. 13.2 & 13.3 (p. 222).

MATERIAL AND OCCURRENCE – Five small penultimate and ultimate pinnae fragments from BB-30 preserved as devolatilized and decarbonized adpressions.

DESCRIPTION – Racheis of penultimate pinnae (PL. 17, Fig. 4) ca. 4.1 mm wide, rather smooth, irregularly striate, with sparse punctae 216 to 325 µm in diameter; racheis of ultimate pinnae arise abruptly to slightly decurrently, longitudinally striate, 0.6 to 1.1 mm wide; ultimate pinnae alternate, arise obliquely at 65 to 75°, linear-lanceolate, up to 28.2 mm long; lateral margins essentially parallel, converge very rapidly near summit to very broadly rounded apex, pinnules alternate, adjoin rachis with entirety of base, nearly perpendicular to axis, generally contiguous, incised only 3/4 to 4/5 pinnule length and so united to base of adjacent pinnules (Pl. 17, Fig. 6), linguaeform, apices markedly broadly rounded, 2.5 to 7.1 mm long, 1.6 to 2.8 mm wide, L:W ratio 1.47 to 2.54; lateral margins usually entire, parallel, straight, may be somewhat concave (due to inrolling into matrix) or falsely crenulate, midveins weakly decurrent, straight to slightly flexuous, 109 to 244 µm wide at base, bifurcate near apex; lateral veins (Fig. 4.5.4; Pl. 17, Fig. 5) markedly delicate, ca. 25 to 84 µm wide, arise at 20 to 30°, extend short distance then fork at open angle (40 to 50°) before turning abruptly to reach lateral margin at 70 to 90°; intersection with lateral margins may result in falsely crenulate or finely lobate margin (Pl. 17, Fig. 9); hairs on abaxial(?) pinnule surfaces (Pl. 17, Fig. 6) linear, sharply acuminate, up to 0.89 mm long, 28 to 50 µm wide at base.

REMARKS – Morphology of the pinnules (especially arrangement of lateral veins) is strikingly similar to a schematic illustration of *Pecopteris herdii* pinnules by Gastaldo and Zodrow (1982). Similarities include: pinnule outline (broadly rounded apices, occasionally falsely crenulate or concave lateral margins), nervation pattern, and presence of abaxial(?) hairs, indicating that specimens may at least have affinity with *P. herdii*.

Although fragmentary, *P.* sp. cf. *P. herdii* can be distinguished from *Lobatopteris* sp. A based on the essentially perpendicular attachment and confluent bases of pinnules, and comparatively delicate and flexuous venation (see Fig. 4.5.4).

Pecopteris sp. A

Pl. 17, Figs. 8, 10, 11; Pl. 18, Figs. 1, 2

MATERIAL AND OCCURRENCE – Seven specimens from BB-25, BB-30 and BB-32 comprising penultimate and ultimate pinnae preserved as devolatilized and decarbonized adpressions.

DESCRIPTION – Racheis of penultimate pinnae (Pl. 17, Figs. 10, 11) up to 2.5 mm wide, with elevated punctae ca. 75 to 375 µm in diameter, up to 2.5 mm wide; penultimate pinnae of indeterminate morphology or dimensions, lateral margins near apex initially converge very rapidly before constricting more gradually to narrowly rounded(?) apex (imparting convex then concave profile).

Racheis of ultimate pinnae arise abruptly, fasciculate, 0.2 to 0.9 mm wide at base, extend very close to apex; ultimate pinnae alternate, arise obliquely at 50 to 90° (ave. ca. 65 to 75°), distant, linear-lanceolate with narrowly rounded, lobate apex, curve gently

apically; *distal ultimate pinnae* (Fig. 4.4.E; Pl. 17, Figs. 10, 11; Pl. 18, Fig. 1) 10.8 to 14.4 mm long, 3.0 to 3.8 mm wide, broadest at base, lateral margins converge gradually; *proximal ultimate pinnae* (Fig. 4.4.F; Pl. 17, Figs. 8, 11; Pl. 18, Fig. 2) up to 45.3 mm long, 3.9 to 8.8 mm wide, broadest at base, lateral margins strikingly parallel.

Pinnules alternate, increasingly decurrent and oblique (60 to 90°) when small, adjoin rachis with entirety of base, distant near tops, bases contiguous or confluent with adjacent pinnules, subtriangular to sublinguaeform, semicircular to subrectangular when small (Pl. 17, Figs. 10, 11; Pl. 18, Fig. 1), straight or subfalcate and curved apically with increasing size (Pl. 17, Figs. 8, 11, Pl. 18, Fig. 2), may be strongly vaulted with inconspicuous compression margin ca. 103 to 156 µm wide; lateral margins subparallel, gently curved to straight, entire or rarely pinnatifid, converge gradually to narrowly or obtusely rounded summits; *entire pinnules of ultimate pinnae* (Fig. 4.4.E, F) 1.1 to 4.4 mm long, 0.9 to 1.9 mm wide, L:W ratio 1.08 to 3.63; *entire pinnules near apices of penultimate pinnae* (Fig. 4.4 H; Pl. 17, Fig. 10; Pl. 18, Fig. 1) 2.3 to 3.5 mm long, 1.0 to 1.6 mm wide, L:W ratio 1.74 to 2.30; *pinnatifid pinnules near apices of penultimate pinnae* (Fig. 4.4.J) 3.6 to 9.7 mm long, 1.6 to 2.7 mm wide, L:W ratio 2.19 to 3.69, lobes 0.6 to 1.2 mm apart.

Midveins repressed, slightly fasciculate, abrupt but increasingly decurrent and broadly curved in small pinnules, ca. 125 to 412 µm wide at base, extend directly to apex (in small pinnules) or bifurcate(?) just beforehand; lateral veins arise at ca. 25 to 45°, arch gently to reach lateral margin at ca. 55 to 70°, simple or dichotomize immediately after arising from midvein.

REMARKS – Although distal frond elements have not been found in organic connection with more proximal elements, that they were originally intimately associated on the same plant is assumed because: (i) entire pinnules near the terminus of penultimate pinnae (Fig. 4.4.H; Pl. 17, Fig. 10; Pl. 18, Fig. 1) are morphologically identical to those of proximal ultimate pinnae (Fig. 4.4.F; Pl. 17, Figs. 8, 11; Pl. 18, Fig. 2); and (ii) tiny pinnules on distal ultimate pinnae (Fig. 4.4.E; Pl. 17, Fig. 10; Pl. 18, Fig. 1) are morphologically identical to those near the apices of proximal ultimate pinnae (Fig. 4.4.F; Pl. 17, Fig. 11; Pl. 18, Fig. 2), and to those on distal ultimate pinnae near the apices of penultimate pinnae (Pl. 17, Fig. 10; Pl. 18, Fig. 2).

The pattern of rapid lobing or differentiation of entire pinnules near apices of penultimate pinna to form pinnatifid then distal ultimate pinnae bears some resemblance to rather abrupt patterns of lobing characteristic of the form-genus *Lobatopteris* (Wagner 1958). In particular, apical penultimate pinnae are morphologically similar to and may have affinity with *Lobatopteris micromiltoni*, a species with somewhat decurrent, semicircular to linguaeform, and relatively small pinnules (see Corsin 1951, pl. 160). However, pinnules of proximal ultimate pinnae from Blanche Brook are less comparable with *L. micromiltoni*, as they are attached to the racheis far less decurrently, and are more subtriangular and elongate than those figured by Corsin (1951). Alternatively, *Pecopteris* sp. A may in fact be a member of the *Pecopteris arborescens* Group, a notoriously difficult group of pecopterids recently revised by Zodrow (1990).

The subtriangular and somewhat apically curved pinnules on proximal ultimate pinna bear some superficial resemblance to pinnules of *Pecopteris plumosa*. However,

these taxa are quite easily differentiated because *P. plumosa* has conspicuously subtriangular pinnules with wider bases and a more open, flexuous venation pattern (Fig. 4.5.5).

Sphenopteris (Brongniart) Sternberg, 1825

Sphenopteris sp. A

Pl. 18, Fig. 5

MATERIAL AND OCCURRENCE – Single penultimate pinna fragment from BB-30 preserved as devolatilized adpression, with vascular strand of rachis pyritized.

DESCRIPTION – Penultimate pinna 42.5 mm long, ca. 37.5 mm wide; rachis delicate, straight to slightly flexuous, with faint longitudinal striae, ca. 1.0 mm wide, central vascular strand ca. 0.2 mm wide; ultimate pinnae with short stalk, alternate, perpendicular or slightly oblique at 70-90°, distant, linear-lanceolate with narrowly rounded apex, 11.2 to 18.9 mm long, 5.0 to 7.9 mm wide; racheis straight, 0.3 to 0.5 mm wide near base; pinnules with tiny but discernible stalks near base of pinnae, more broadly attached apically, decurrent and oblique at 35 to 70°, distant, subovate, 1.2 to 3.6 mm long, 0.8 to 2.1 mm wide, laminae moderately incised by thin, acuminate sinuses resulting in terminal lobe and up to three pairs of lateral lobes, lateral lobes broadly attached, either broadly rounded, triangular and squat, or somewhat lanceolate with pointed apices.

REMARKS – The morphology of foliage and presence of stalked pinnae and pinnules indicates possible affinity with the foliar form-genus *Sphenopteris*.

cf. *Sphenopteris* sp.

Pl. 17, Fig. 7

MATERIAL AND OCCURRENCE – Single apical fragment of ultimate(?) pinna from BB-25 preserved as "naturally macerated" volatilized adpression (veins coalified).

DESCRIPTION – Pinna subtriangular; rachis 0.4 mm wide, bordered by thin wing of lamina, terminus of rachis comparatively robust, stiffened, longitudinally striated; pinnules stalked, alternate to sub-opposite, decurrent, inserted obliquely at ca. 20 to 30°, membranous with thin laminae, cuneiform to fan like, 3.9 to 5.9 mm long, 1.2 to 2.9 mm wide, broadest at distal margin, lateral margins entire, straight; distal margins somewhat convex, digitate or dentate, divided into 2 to 7 "teeth"; teeth obtusely rounded, ca. 0.4 mm wide, separated by deeply incised, narrowly pointed sinuses, longest near middle of distal margin, decrease in number in apical pinnules; midveins strongly decurrent, 106 to 145 µm wide, dichotomize 1 to 4 times at acute angles (20 to 40°), each vein extending nearly straight before terminating at distal end of single tooth.

REMARKS – The taxonomic position of this specimen is impossible to ascertain without larger, better preserved material. Given that pinnules are stalked, the specimen is tentatively included in the heterophyllous foliage form-genus *Sphenopteris*. In particular, the specimen bears some resemblance to *Sphenopteris coemansii* illustrated by Brousmiche (1983, p. 311, pl. 84, figs. 1–4) and Josten (1991, p. 215, pl. 98, figs. 1-2a), and may represent the apical end of this or an affine taxon. The stiffened rachis which terminates the specimen may represent a strobilus(?) (Pl. 17, Fig. 7).

Fern frond racheis

Pl. 16, Figs. 3, 6

MATERIAL AND OCCURRENCE – Abundant stem fragments from BB-30 preserved as (occasionally partially pyritized) devolatilized or decarbonized adpressions.

DESCRIPTION – Racheis unbranched, up to 22.0 cm long, 5.5 to 28.0 mm wide, irregularly punctate, occasionally pubescent, longitudinal striae inconspicuous and discontinuous; punctae circular, 0.1 to 0.5 mm in diameter (ave. 0.2 mm); hairs acuminate, straight to slightly curved, stiff(?), 0.5 to 3.6 mm long.

REMARKS – Racheis are interpreted as isolated, pubescent and punctate axes of *Pecopteris* and *Lobatopteris* fronds. Apparently no form-genus name exists for adpressed stems, but when anatomically preserved as petrifactions they are referred to as *Psaronius* (Stidd 1971, Stewart and Rothwell 1993). *Psaronius* fronds can be very large and have multiple orders of branching, which confounds efforts to determine from which part of the frond each specimen was derived. It is suffice to note that wider axes represent racheis from proximal parts of the frond.

4.4 Division PTERIDOSPERMOPHYTA

Order MEDULLOSALES

Alethopteris Sternberg, 1825

cf. *Alethopteris* sp.

Pl. 18, Fig. 4

MATERIAL AND OCCURRENCE – Single pinnule fragment from BB-30 preserved as devolatilized adpression.

DESCRIPTION – Pinnule 10.6 mm long (base nor apex preserved), 4.4 mm wide, strongly vaulted; lateral margins straight, parallel, converge slightly towards apex; midvein prominent, strongly repressed, longitudinally striate, 0.2 mm wide; lateral veins prominent, arise nearly perpendicular to midvein, arch slightly to reach lateral margin at ca. 90°, ca. 90 µm wide, equidistant, ca. 0.2 mm apart, unbranched or dichotomize once at very low angle near midvein.

REMARKS – The dense, nearly perpendicular venation, repressed midvein, and strongly vaulted lamina are all characteristics of the form-genus *Alethopteris*.

Form-genus *Cyclopteris* Brongniart, 1828

***Cyclopteris* spp.(?).**

Pl. 18, Figs. 3, 7, 8

MATERIAL AND OCCURRENCE – Three specimens (two pinnules) from BB-30 and BB-32 preserved as decarbonized, devolatilized or "naturally macerated" (occasionally partially pyritized) volatilized adpressions.

DESCRIPTION – Pinnules isolated, laminae delicate, often asymmetrical, orbiculate, ovate or semicircular, bases truncate, margins entire, 22.2 to 35.6 mm long, 18.8 to >37.0 mm wide, broadest at base or near middle; veins prominent, longitudinally striate, nonflexuous, distant, ca. 0.3 mm wide at base, enter near middle of base, extend apically

and arch gently or broadly (radiate) to reach lateral margin at 70-90°, dichotomize five to seven times at very low angles (10-15°), nervation density 23 to 33/cm.

REMARKS – According to criteria of Cleal and Zodrow (1989), Cleal et al. (1990) and Cleal and Shute (1995), large, orbiculate pinnules referred to *Cyclopteris* sp. are attached to primary racheis of *Laveineopteris* below the main bifurcation (see Cleal and Shute 1995, figs. 4, 5; Laveine 1997, fig. 4). It is, however, very difficult to refer isolated cyclopterid pinnule adpressions to species unless intimately associated with identifiable "normal" lateral pinnules or forma *impar*-type pinnules

Pinnules probably have affinity with *Cyclopteris orbicularis* (see Cleal and Thomas 1994, pl. 17, fig. 1). They resemble pinnules figured by Bell (1962, pl. 32, figs. 3, 4) that he postulated might have been attached to stems bearing *Neuropteris* (=*Laveineopteris*) *tenuifolia* foliage. A single pinna comparable to this taxon was recovered from BB-30, but *L. tenuifolia* forms much of the plant litter at BB-14. Additionally, pinnules compare with cyclopteroid-type pinnules that Bell (1938, pl. 52, fig. 2) attributed to *Neuropteris* (=*Macroneuropteris*) *scheuchzeri*, although material from Blanche Brook lacks any evidence of the hairs that Bell used to establish this affinity.

The radiating, gently to broadly arching, and non-flexuous habit of veins within the material differentiates them from cyclopteroid-type (i.e., not "true" *Cyclopteris* sp.) pinnules interpreted as having affinity with *Neuropteris semireticulata* (Fig. 4.8.6 and 4.8.8; Pl. 18, Fig. 6, Pl. 23, Figs. 6, 8).

Laveineopteris Cleal, Shute and Zodrow (1990)

Laveineopteris rarinervis (Bunbury) Cleal, Shute and Zodrow, 1990

Fig. 4.6.1 to 4.6.3, 7, 8 (p. 101); Pl. 18, Figs. 9 to 13; Pl. 19, Figs. 1 to 4, 9

1930 *Neuropteris Nikolausi*. Bertrand, pp. 21-23; pl. 8, figs. 1-2a; pl. 8 bis, figs. 1-2.

1938 *Neuropteris rarinervis*. Bell, pp. 58-59; pl. 52, fig. 3; pl. 53, figs. 1, 2.

1953 *Neuropteris attenuata*. Havlena, pp. 133-140; pl. 1, figs. 1-5; pl. 2, figs. 1-3.

1953 *Neuropteris rarinervis*. Havlena, pl. 1, fig. 6.

1959 *Neuropteris rarinervis*. Crookall, p. 122-127; text-figs. 43 (p. 124), 44 (p. 126), 64g, h (p. 197), pl. 30, figs. 1-3, pl. 31, figs. 1-3.

1962 *Neuropteris rarinervis*. Bell, pp. 43-44; pl. 32, figs. 1, 2; pl. 35; pl. 36, figs. 1, 3.

1966 *Neuropteris rarinervis*. Bell, pl. 30, figs. 7, 8; pl. 32, figs. 1, 2; pl. 33, fig. 7.

1967 *Neuropteris rarinervis*. Laveine, pp. 181-190; text-fig. 31a-i (p. 183); pl. G, figs. 2, 2a; pl. N, fig. 4a, pl. O, figs. 1, 1a, 1b; pl. 40, figs. 1-4a; pl. 41, figs. 1-4a; pl. 42, figs. 1-3a, pl. 43, figs. 1-3, pl. 44, figs. 1-5a; pl. 45, figs. 1-2a, 4-5a; pl. 46, figs. 1-2a, pl. 1-6a.

1969 *Neuropteris rarinervis*. Darrah, pp. 101-102; pl. 20, fig. 2.

1975 *Neuropteris rarinervis*. Doubinger and Germer, pp. 9-10; text-fig. 5 (p. 9); pl. 3, fig. 4.

1977 *Neuropteris attenuata*. Remy and Remy, p. 255; pl. 136, figs. a-d (p. 254).

1986 *Neuropteris rarinervis*. Zodrow and Vasey, p. 213; text-fig. 5 (p. 212).

1991 *Neuropteris attenuata*. Josten, pp. 323-324; text-fig. 209 (p. 324); table 22 (p. 332-333), pl. 188, figs. 1, 1a, 1b.

1994 *Laveineopteris rarinervis*, Cleal and Thomas, p. 112; text-fig. 53 (p. 113); pl. 17, fig. 4 (p. 111).

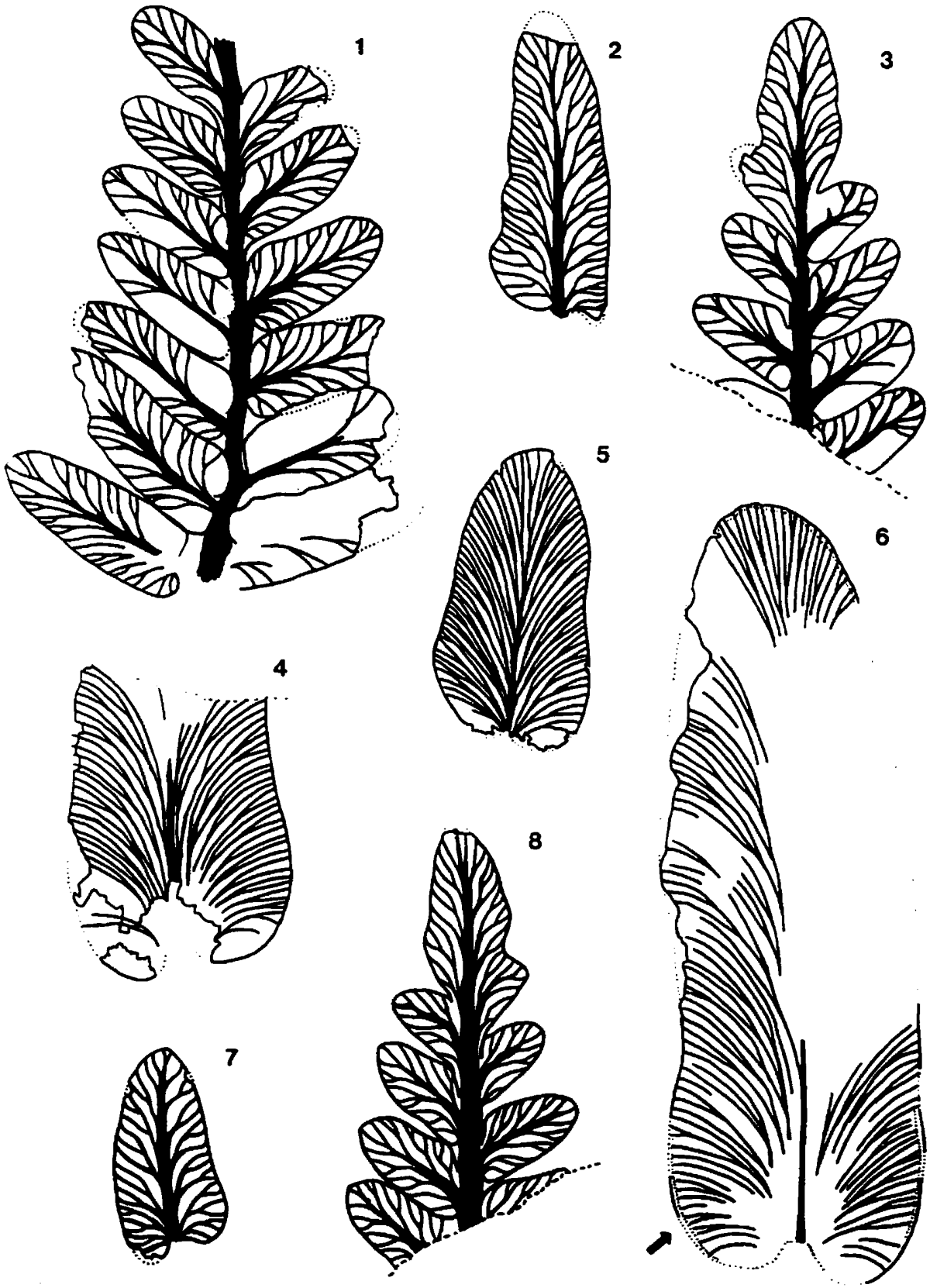
MATERIAL AND OCCURRENCE – Abundant isolated pinnules and penultimate and ultimate pinnae fragments from BB-14 preserved as devolatilized and decarbonized adpressions. Cuticles well preserved.

DESCRIPTION – Racheis of penultimate pinnae (Pl. 19, Fig. 2) ca. 1.0 mm wide, with longitudinal striae or ribs ca. 0.2 mm apart; ultimate pinnae (Fig. 4.6.1, 3, 8; Pl. 18, Figs. 9, 11, 12; Pl. 19, Figs. 1, 9) linear-lanceolate, obtusely rounded apex, distant, contiguous or slightly overlapping, 1.5 to 2.2 cm long, 5.8 to 8.8 mm broad, bearing lateral pinnules and culminating in terminal pinnule; racheis (Pl. 19, Fig. 1) 0.5 to 0.9 mm wide, longitudinally striate with ribs ca. 79 to 156 µm apart, end as "midvein" of terminal pinnule; lateral pinnules stalked but increasingly sessile apically (Fig. 4.6.1, 3, 8; Pl. 19, Fig. 1), alternate to sub-opposite, arise obliquely, contiguous or overlapping, linguaeform, subovate to subrectangular, coriaceous, 2.8 to 11.8 mm long, often longer on acroscopic side of pinna, 1.7 to 4.9 mm wide, L:W ratio 1.53 to 2.65, ratio higher in proximal pinnules, bases semicordate with basiscopic and acroscopic auricles, acroscopic auricle commonly overlapping rachis, frequently with prominent "compression margin" comprising striae arranged oblique to lateral margin (Pl. 19, Fig. 9); lateral margins nearly straight, undulate when pinnule very slightly pinnatifid or auricles well developed; midveins prominent, fasciculate, somewhat flexuous, 0.2 to 0.5 mm wide at base, extending ca. 3/4 to 4/5 up pinna before bifurcating; lateral veins prominent, widely

spaced, fasciculate, slightly flexuous, 56 to 125 µm wide, arise at 25 to 35°, extend nearly straight or arch to reach lateral margin at 40 to 80° (angle decreasing apically) where they curve apically to merge with "compression margin", unbranched (near tops of pinnules) or bifurcate 1 to 3 (rarely 4) times at wide angles, nervation density 19 to 35/cm (decreasing apically), in broadly attached, decurrent pinnules near apices thin subveins arise directly from rachis and enter basiscopic side of pinnule (Fig 4.6.1; Pl. 19, Fig. 1); terminal pinnules (Fig. 4.6.3, 8; Pl 18, Fig. 11) trapezoidal to hastate, pinnatifid near base, with undulate lateral margins that converge to broadly or obtusely rounded apices.

REMARKS - Material within the BBA is characterized by very small pinnules that strongly resemble *Neuropteris microphylla*, which was synonymized with *N. rarinervis* by Laveine (1967). In addition, pinnules are characterized by fasciculate lateral veins that curve apically just before terminating (Fig. 4.6.7) and merging with prominent "compressions margins" comprising oblique "striations" (Pl. 19, Figs. 1, 9). Similar observations were made by Oestry-Stidd (1979, p. 38) from anatomically preserved specimens, who wrote that "tracheids are contorted where the veins end at the pinnule margin and resemble the bundle structure of hydathodes." (Hydathodes are water-excreting epidermal structures.) Although this "compression margin" could be a very useful in identification of *L. rarinervis*, it apparently has yet to be recognized (or at least documented) in adpressed specimens.

Lateral margins of some elongate pinnules with comparatively high nervation densities are pinnatifid(?) with fairly regular undulations that may represent initial stages of lobing (Fig. 4.6.2, Pl. 18, Figs. 10, 13; see also Remy and Remy 1977, fig. 136d, p.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(*previous page*) Figure 4.6. (1.) Ultimate pinna of *Laveineopteris rarinervis*, with sparse venation characteristic of taxon; note small subveins entering basiscopic side of uppermost (sessile) pinnules directly from rachis rather than arising from midvein; BB-96-14-44, x5. (2.) Isolated, mature pinnule of *L. rarinervis* with comparatively dense venation; left (acroscopic?) lateral margin slightly lobate; BB-96-14-21, x5. (3.) Apex of ultimate pinna of *L. rarinervis*; BB-96-14-18, x5. (4.) Pinnule fragment of cf. *Laveineopteris tenuifolia* with dense, gently arching venation; BB-96-14-24, x5. (5.) Small pinnule of cf. *L. tenuifolia*; BB-96-14-9, x5. (6.) Large, elongate pinnule of cf. *L. tenuifolia*; compression margin (arrow); BB-96-14-45, x5. (7.) Isolated pinnule of *L. rarinervis*; note lateral veins curve apically upon reaching lateral margin; BB-96-14-42b, x5. (8.) Apex of ultimate pinna of *L. rarinervis*; pinnules increasingly sessile apically; BB-96-14-16, x5.

254). These pinnules may have been inserted near apices of penultimate pinnae (cf. Fig. 4.4.J; see also Crookall 1959, fig. 43, p. 124; Bell 1966, pl. 30, fig. 7; Laveine 1967, pl. 44, figs. 4, 4a). Alternatively, they may have been inserted near the base of proximal ultimate pinnae (cf. Fig. 4.4.G; see also Laveine 1967, pl. 42, figs. 2, 2a).

cf. *Laveineopteris tenuifolia* (Sternberg) Cleal, Shute and Zodrow, 1990

Fig. 4.6.4 to 4.6.6 (p. 101); Pl. 19, Figs. 5 to 8; Pl. 20, Figs. 1, 2, 4, 5

1930 *Neuropteris tenuifolia*, Bertrand, pp. 18-20; pl. 1, fig. 1; pl. 2, figs. 1, 2; pl. 3, figs. 1, 2; pl. 4, figs. 1-1b; pl. 5, figs. 1-1b; pl. 6, figs. 1-3.

1938 *Neuropteris tenuifolia*, Bell, p. 54; pl. 47, figs. 1-3.

1953 *Neuropteris tenuifolia*, Havlena, pp. 145-147; pl. 3, figs. 3-6; pl. 6, fig. 3; pl. 7, figs. 3, 4.

1959 *Neuropteris tenuifolia*, Crookall, p. 117-121; text-figs. 42 (p. 119), 63f, k (p. 196); pl. 29, figs. 1-4.

1962 *Neuropteris tenuifolia*, Bell, p. 42; pl. 34, figs. 3, 4; pl. 36, fig. 2.

1966 *Neuropteris tenuifolia*, Bell, pl. 13, fig. 7; pl. 14, fig. 9; pl. 17, fig. 1.

1967 *Neuropteris tenuifolia*, Laveine, pp. 166-176; text-fig. 29a-e (p. 168); pl. B, figs. 2, 2a; pl. N, fig. 1, 2?, 2a?; pl. 30, figs. 1-4a; pl. 31, figs. 1-5; pl. 32, figs. 1-4; pl. 33, figs. 1-2a, 4-6; pl. 34, figs. 1-5a.

1969 *Neuropteris tenuifolia*, Darrah, pp. 100-101; pl. 45, figs. 3-4.

1975 *Neuropteris tenuifolia*, Doubinger and Germer, p. 5; pl. 1, figs. 1, 2.

1977 *Neuropteris tenuifolia*, Remy and Remy, p. 252; text-fig. 135, figs. a-c (p. 253).

1986 *Neuropteris tenuifolia*, Zodrow and Vasey, p. 213; text-fig. 6-1, 2, 3-8 (p. 214), text-fig. 7 (p. 215).

1991 *Neuropteris tenuifolia*, Josten, pp. 316-318, text-fig. 203 (p. 317); table 22 (p. 332-333); pl. 181, figs. 1, 1a; pl. 182, figs. 1, 1a, 1b.

1994 *Laveineopteris tenuifolia*, Cleal and Thomas, p. 114; text-fig. 53a (p. 113); pl. 17, fig. 5 (p. 111).

MATERIAL AND OCCURRENCE – Abundant isolated pinnules from BB-14 preserved as decarbonized, devolatilized or "naturally macerated" (occasionally partially pyritized) volatilized adpressions; single incomplete ultimate pinna from BB-30 preserved as devolatilized adpression. Cuticles well preserved.

DESCRIPTION – Ultimate pinna (Pl. 20, Fig. 1) linear-lanceolate, 8.4 cm long (base nor apex preserved), ca. 3.1 cm wide, lateral margins straight and parallel; rachis ca. 1.84 mm wide, with longitudinal striae and prominent ribs ca. 0.2 mm apart; lateral pinnules stalked but increasingly sessile apically, alternate, slightly oblique at 75 to 80°, ca. 45° apically, distant, straight to subfalcate, round or subovate to linguaeform or elongate-

triangular, 5.2 to 25.4 mm long, 3.0 to 8.6 mm wide, broadest at base, L:W ratio 1.26 to 3.08, ratio highest in proximal pinnules, bases cordate to semicordate, basiscopic auricles increasingly prominent with maturity (Pl. 19, Fig. 6; Pl. 20, Fig. 1); compression margin (Fig. 4.6.6; Pl. 20, Figs. 2, 4) prominent, ca. 0.1 to 0.2 mm wide, smooth; lateral margins parallel, converge slightly near broadly to obtusely rounded apex, with diagnostic shallow indentation 1/4 to 1/2 up pinnule (Fig. 4.6.4 to 4.6.6; Pl. 19, Fig. 6; Pl. 20, Figs. 1, 2, 5); midveins inconspicuous, repressed, finely striate, 0.2 to 0.6 mm wide at base, straight, extend ca. 3/5 to 9/10 (ave. 4/5) pinnule length; lateral veins dense but distant, distinct, 75 to 100 μm wide at lateral margin, arise at 10 to 25°, ascend straight before gently arching to reach lateral margin at 50 to 90° (ave. 75°) where they merge with compression margin, divide very near midvein, subsequently dichotomize at very low angle 1 to 3 (rarely 4) more times, nervation density 32 to 47/cm.

REMARKS – With the exception of a single ultimate pinna fragment, specimens are recovered only as detached pinnules. Although this trait may be paleoecologically significant in demonstrating the caducous nature of this species, it does complicate accurate taxonomic assignment. Many specimens are characterized by a prominent and fairly diagnostic smooth, compression margin (Fig. 4.6.6; Pl. 20, Figs. 2, 4). Although this feature can be recognized in figures of *L. tenuifolia* by several authors (eg. Bell 1962, pl. 36, fig. 2; Cleal and Thomas 1994, pl. 17, fig. 5), surprisingly only Bell (1938, p. 42) has acknowledged its existence.

Although the material from Blanche Brook has tentatively been referred to cf. *L. tenuifolia*, some specimens bear semblance to *Neuropteris bourozii* Laveine (see Laveine

1967, p. 152, pls. 23 to 25), a rare species restricted to lower Duckmantian strata of western Europe (Cleal and Shute 1995). Cuticles recovered from adpressions of cf. *L. tenuifolia* from Blanche Brook were briefly examined and, on preliminary analysis, are identical to cuticles of *L. tenuifolia* described by Barthel (1962). Cuticles have not been described from *N. bourozii* (Cleal and Shute 1995), so cuticular comparison is not yet possible.

Form-genus *Linopteris* Presl, 1838

***Linopteris neuropteroides* (Gutbier) Zeiller, 1899**

Fig. 4.7.1 and 4.7.2 (p. 107); Pl. 20, Figs. 3, 6 to 11; Pl. 21, Figs. 1, 5

1930* *Linopteris neuropteroides* var. *minor*, Bertrand, pp. 32-34; pl. 16, figs. 1-3; pl. 17, figs. 1-3; pl.18, figs. 1a-b.

1938 *Linopteris neuropteroides* var. *major*, Bell, p. 66; pl. 61, figs. 1-4.

1959 *Linopteris neuropteroides*, Crookall, p. 209-211; text-figs. 71 (p. 210), 72d (p. 212); pl. 48, fig. 4.

1966 *Linopteris neuropteroides* var. *major*, Bell, pl. 14, figs. 4, 5.

1967 *Linopteris neuropteroides*, Laveine, pp. 279-284; text-fig. 45a-c (p. 280); pl. 79, figs. 1a-10; pl. 83, figs. 3, 3a.

1977 *Linopteris neuropteroides* var. *major*, Remy and Remy, p. 268; pl. 147, figs. a-b (p. 269).

1977* *Linopteris neuropteroides* var. *neuropteroides*, Remy and Remy, p. 268; pl. 148, figs. a-b (270-271).

1991 *Linopteris neuropteroides*, Josten, pp. 341-343; text-figs. 220 (p. 342), 221 (p. 342); table 24 (p. 346); pl. 205, figs. 1-2a; pl. 206, figs. 1-4a.

MATERIAL AND OCCURRENCE – Numerous isolated pinnules from BB-19 preserved as devolatilized and decarbonized adpressions.

DESCRIPTION – Pinnules caducous, typically arcuate or subfalcate, occasionally straight and rotund or sublinguaeform to subovate, bases truncate to slightly cordate, 9.1 to 25.2 mm long (ave. 18.3, n=19), 5.9 to 9.8 mm wide (ave. 8.1, n=27), broadest between base or 1/2 up pinnule, L:W ratio 1.53 to 2.86 (ave. 2.32, n=19), may have subtle compression margin 94 µm wide, rarely with punctae(?) or hairs on lamina surface; lateral margins entire, subparallel near base, one or both curve inward near summit to broadly or (infrequently) narrowly rounded apex; punctae(?) (Pl. 21, Fig. 1) 35 µm in diameter, hairs (Pl. 21, Fig. 5) straight to slightly bent, ca. 150 µm long, oriented oblique to lateral margin; midveins repressed and somewhat inconspicuous, with faint longitudinal striae, 0.1 to 0.3 mm wide near base, extend ca. 2/3 to 3/4 up pinnule; lateral veins thin, typically 50 but up to 100 µm wide, arise at 8-15°, arch to reach lateral margin at 60 to 90° (ave. ca. 75-85°), anastomose to form meshwork of elongate, thin, acutely pointed areolae (Fig. 4.7.1, 2.; Pl. 21, Figs. 1, 5) that decrease in size upon approaching lateral margin, nervation density ca. 53/cm.

REMARKS – Paripinnate pteridosperm foliage (including *Paripteris* and *Linopteris*) frequently is recovered as only isolated pinnules, attesting to the caducous nature of the group. As these taxa have a diverse array of pinnule morphologies depending on the

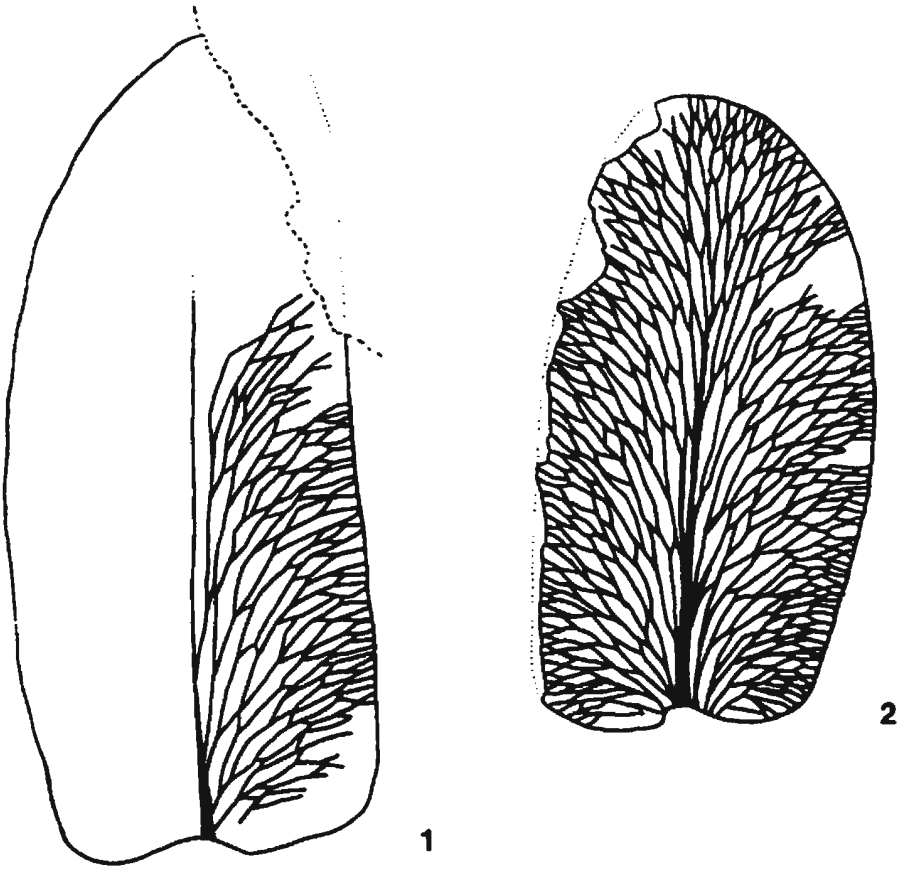

Figure 4.7. Schematic line drawings of *Linopteris neuropteroides*. (1.) Isolated, subfalcate pinnule with anastomosing venation characteristic of taxon; BB-96-19-40, x3. (2.) Isolated pinnule tentatively referred to *L. neuropteroides*; venation slightly more flexuous than typical of pinnules from BBA (see discussion in text); BB-96-19-24, x3.

insertion point on the original frond (see especially Laveine 1967, pl. 79), it is perhaps expected that pinnules with variable profiles from Blanche Brook have been included in *L. neuropteroides*.

Material within the BBA compares most closely with *L. neuropteroides* var. *minor* described by Potonié (1904; 15 to 22 mm long, 6 to 8 mm wide, straight or only slightly arched). Apparently Bell (1938, 1966) only identified pinnules of var. *major* in

Sydney Coalfield, although some figured specimens (eg. Bell 1938, pl. 61, fig. 1) more closely resemble *L. neuropteroides* var. *minor*.

One very well preserved pinnule (Fig. 4.7.2; Pl. 20, Fig. 6; Pl. 21, Fig. 5) has markedly thicker veins that seem slightly more flexuous than those of all other specimens. Although these differences may justify inclusion within another taxon, it is significant to note that this specimen is the only one found preserved in mudstone, while all others are preserved in siltstone. Thus taphonomic factors may in fact be responsible for the apparent differences.

Macroneuropteris Cleal, Shute and Zodrow, 1990

Macroneuropteris scheuchzeri (Hoffmann) Cleal, Shute and Zodrow 1990

Pl. 21, Figs. 3, 4

1930 *Neuropteris Scheuchzeri*, Bertrand, pp. 24-29; pl. 9; pl. 10, figs. 1, 2; pl. 11, figs. 1-3; pl. 12, figs. 1, 1a.

1938 *Neuropteris scheuchzeri*, Bell, pp. 57-58; pl. 51, figs. 2-4; pl. 52, fig. 1.

1938 *Neuropteris scheuchzeri* forma *angustifolia*, Bell; pl. 50, fig. 3; pl. 51, fig. 5.

1959 *Neuropteris Scheuchzeri*, Crookall, pp. 178-188; text-figs. 57 (p. 181), 58 (p. 183), 59 (p. 184), 65a, b (p. 198); pl. 41, figs. 1, 2.

1962 *Neuropteris scheuchzeri* forma *angustifolia*, Bell, p. 44; pl. 37, figs. 1, 2, 5.

1966 *Neuropteris scheuchzeri*, Bell, pl. 26, fig. 10; pl. 33, fig. 2.

1967 *Neuropteris scheuchzeri*, Laveine, pp. 237-246; text-fig. 41 a-c; pl. F, figs. 1, 1a, 2, 2a; pl. J, figs. 1, 1a; pl. N, fig. 3;

1977 *Neuropteris scheuchzeri*, Remy and Remy, p. 261; pl. 140, figs. b-d (p. 260).

1991 *Neuropteris scheuchzeri*, Josten, p. 331; text-fig. 215 (p. 331); table 22 (p. 332-333); pl. 197, figs. 1, 1a, 2; pl. 198, figs. 1, 1a.

1994 *Macroneuropteris scheuchzeri*, Cleal and Thomas, text-fig. 50a (p. 107); pl. 18, fig. 2 (p. 117).

MATERIAL AND OCCURRENCE – Fragment of single pinnule from BB-14 preserved as devolatilized (part) and decarbonized (counterpart) adpressions.

DESCRIPTION – Pinnule very elongate, slightly curved, 35.7 mm long (base nor apex preserved), ca. 6.4 mm wide, L:W ratio >5.6, villous; lateral margins entire, curved but parallel; midveins repressed, indistinct, straight, extending much of pinnule length; lateral veins very dense, 35 to 60 µm wide, arise at ca. 10 to 15°, arch broadly to reach lateral margin at 70 to 85°, dichotomise 3 to 4 times, nervation density ca. 39/cm; villi (Pl. 21, Fig. 3) abundant, scattered, stiff, 0.9 to 1.8 mm long, oriented more or less apically.

REMARKS – The dense venation, pinnule dimensions and presence of abundant, stiff villi on the pinnule surface clearly indicates reference to *M. scheuchzeri*.

Neuropteris (Brongniart) Sternberg, 1825

Neuropteris semireticulata Josten, 1962

Figs. 4.8.1 to 4.8.8 (p. 112); Pl. 18, Fig. 6; Pl. 21, Figs. 6, 7; Pl. 22, Figs. 1 to 13; Pl. 23, Figs. 1 to 10

1962 *Neuropteris semireticulata*, Josten, pp. 39-40; text-fig. 4f-k (p. 37); pl. 3, figs. 2-5.

1967 *Neuropteris semireticulata*, Laveine, pp. 211-215; text-fig. 36 (p. 212); pl. 57, figs. 1-6a.

1967* *Neuropteris parvifolia*, Laveine, pp. 207-211; text-fig. 35 (p. 208); pl. 56, figs. 1-4a.

1977 *Neuropteris semireticulata*, Remy and Remy, p. 255; text-fig. 138a, b, c? (p. 257).

1991 *Neuropteris semireticulata*, Josten, pp. 328-329; text-fig. 212, 213 (p. 327); table 22 (pp. 332-333); pl. 194, figs. 1-2a; pl. 195, fig. 1.

MATERIAL AND OCCURRENCE – Abundant isolated pinnules (including "normal" lateral pinnules, forma *impar*-type and cyclopteroid-type) and ultimate pinnae from BB-25 and BB-30 preserved as decarbonized, devolatilized and "naturally macerated" (occasionally partially pyritized) volatilized adpressions. Cuticles well preserved.

DESCRIPTION – "Normal" lateral pinnules: Ultimate pinnae imparipinnate, straight to slightly curved, linear-lanceolate to elongate-triangular, 4.2 to 9.0 cm long, ca. 15.0 to 24.5 mm wide, broadest near base; lateral margins nearly parallel or gradually converging to acutely or obtusely rounded apices; racheis longitudinally striate, 0.6 to 1.8 mm wide, culminate as "midvein" of terminal pinnule; lateral pinnules stalked, increasingly sessile apically (Pl. 21, Figs. 6, 7; Pl. 22, Figs. 5, 13), alternate to sub-opposite, arise perpendicular but increasingly oblique and decurrent apically, generally distant but sometimes contiguous, linguaeform to subovate or subtriangular (Pl. 22, Fig. 13), 5.2 to 18.2 mm long, 2.8 to 8.4 mm wide, perhaps longer and narrower on one side of pinna, L:W ratio 1.31 to 3.46 (ave. 1.92, n=126), ratio highest proximally, bases semicordate,

with prominent acroscopic auricle overlapping rachis (Fig. 4.8.1; Pl. 22, Figs. 1, 5, 10), basiscopic auricle contiguous with or underlies(?) rachis; lateral margins straight to slightly curved apically in elongate pinnules, parallel or constrict gradually throughout length before converging to broadly or obtusely rounded; midveins prominent, fasciculate, very flexuous, 0.3 to 0.6 mm wide at base, extend ca. 3/4 to 9/10 (ave. 4/5) up pinnule; lateral veins prominent, fasciculate, 44 to 190 µm wide, arise at open angles (ca. 20 to 30°), extend apically before arching to reach lateral margin at 70 to 90°, conspicuously flexuous to pseudo-reticulate, approach very close to *but almost never touch* adjacent veins (Fig. 4.8.), bifurcate at open angles 1 to 4 times, 24 to 34/ cm (ave. ca. 31); terminal pinnule (Pl. 22, Figs. 2 to 5, 9, 13; Pl. 23, Fig. 9) rhombic to deltoid, pinnatifid near base, either short and blunt with broadly rounded apex or elongate with narrowly rounded apex.

Forma *impar*-type pinnules: Racheis up to 1.8 mm wide, with longitudinal striae or ribs ca. 0.4 mm apart; pinnule stalks longitudinally striate, short, ca. 0.6 to 0.8 mm wide, arising nearly perpendicular or oblique (up to 50°) to rachis; pinnules (Fig. 4.8.3 to 4.8.5; Pl. 22, Figs. 6, 8, 11, 12; Pl. 23, Figs. 1 to 4, 7), of various profiles, typically curved apically and asymmetrical with larger basiscopic side, hastate, subtriangular to subovate, apices narrowly to broadly rounded, bases semicordate with prominent auricle(s), 18.6 to 35.2 mm long, 9.1 to 17 mm wide, L:W ratio 2.05 to 2.35; midvein somewhat flexuous, broadly curved, extends 4/5 to very near pinnule summit where ca. 0.3 mm wide; lateral veins fasciculate or longitudinally striate, arise at 10 to 25° where 170 to 290 µm wide, arching broadly to reach lateral margin at 80 to 90° where 47 to 162

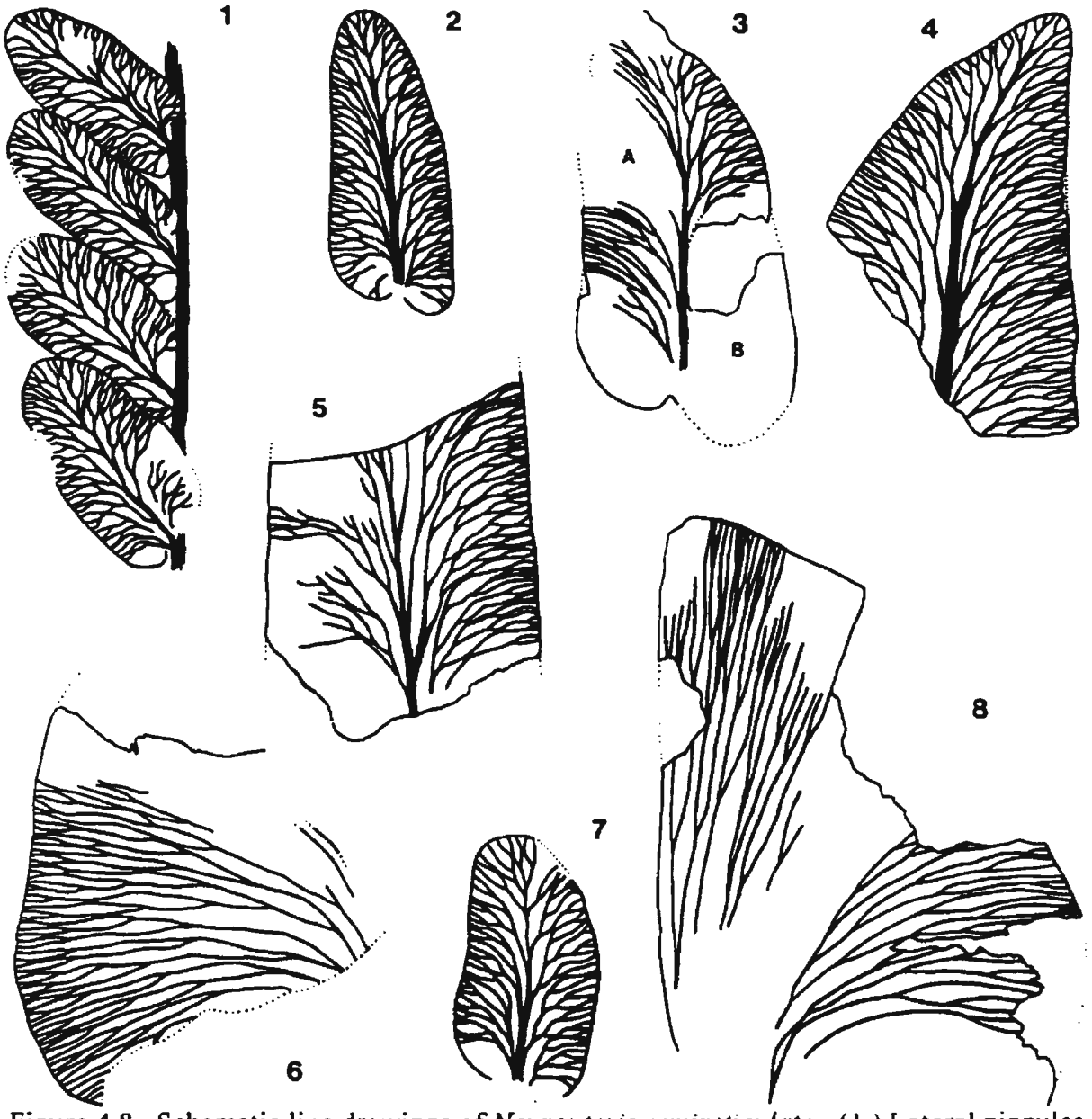

Figure 4.8. Schematic line drawings of *Neuropteris semireticulata*. (1.) Lateral pinnules of ultimate pinna with flexuous to pseudo-reticulate venation diagnostic of taxon; BB-96-25-38, x3. (2.) Isolated "normal" lateral pinnule; BB-94-30-53, x2.5. (3.) Forma *impar*-type pinnule demonstrating that venation on acroscopic side (A) considerably more dense and less flexuous than on basiscopic side (B); BB-96-30-89, x2.5. (4.) Apex of large forma *impar*-type pinnule; BB-96-30-133, x3. (5.) Forma *impar*-type pinnule with dense venation; BB-97-30-181, x3. (6.) Fragment of cyclopteroid-type pinnule; slightly flexuous venation hints at affinity with *N. semireticulata*; BB-96-25-29, x3. (7.) Isolated "normal" lateral pinnule; BB-96-30-66, x2.5. (8.) Cyclopteroid-type pinnule with slightly flexuous venation; BB-94-30-49, x2.

μm wide, dichotomize 2 to 5 times (ave. 3 to 4) at low angle, nervation density 27 to 33/cm, conspicuously flexuous to pseudoanastomosing and widely spaced on basiscopic side, far less flexuous, denser and more broadly arching on acroscopic side.

Cyclopteroid-type pinnules: Pinnules (Fig. 4.8.6, 4.8.8; Pl. 18, Fig. 6; Pl. 23, Figs. 6, 8) isolated, asymmetrical, orbicular or approximately pentagonal, apex broadly or narrowly(?) rounded, base cordate with prominent auricles, ca. 32.0 to 40.0 mm long, 30.1 to 62.0 mm wide, broadest between 1/4 way up and summit; 3 to 4 longitudinally striate to fasciculate veins 0.2 to 0.5 mm wide enter pinnule near middle of base, extend apically before arching broadly to reach lateral margin at 50 to 90° and between 112 to 200 μm wide, flexuous but distant, dense but distinct, dichotomize four to eight times at acute angles (ca. 20°), nervation density ca. 27 to 32/cm.

REMARKS – Josten (1962) and Laveine (1967) documented a transition in venation habit during the Westphalian from *Neuropteris obliqua* (open)→*N. parvifolia* (slightly flexuous)→*N. semireticulata* (flexuous or pseudoanastomosing)→*Reticulopteris muensteri* (fully reticulate). Zodrow and Cleal (1993) suggested that increasing flexuosity with time may have been a floral response to intensifying drier (climatic or edaphic) conditions during the Duckmantian and Bolsovian. Increased vein sinuosity would have enhanced tracheid-mesophyll contact to effectively make the plant more efficient at water distribution (Zodrow and Cleal 1993).

Compound fronds of *Neuropteris sensu stricto* are "bifurcate semipinnate" (*sensu* Laveine 1997), with tri- or rarely quadripinnate branches borne from a main bifurcation of the primary rachis (Zodrow and Cleal 1988; Cleal et al. 1990; Cleal and Shute 1995,

Laveine 1997). "Normal" lateral pinnules were inserted on ultimate pinnae (culminate in terminal pinnules) above the main bifurcation, while conspicuously larger, somewhat asymmetrical pinnules were inserted on the primary rachis below the main bifurcation either on uni- or bipinnate axes (forma *impar*-type), or directly to the primary rachis (cyclopteroid-type) (Laveine 1997, fig. 19, p. 179).

The majority of "normal" lateral pinnules from Blanche Brook clearly conform to the concept of *N. semireticulata*, with semi-cordate bases, flexuous midveins and pseudoanastomosing lateral veins that nearly ***but almost never*** touch adjacent veins. However, specimens with slightly less flexuous lateral veins may compare more closely with *N. parvifolia* (see Laveine 1967). *N. obliqua* also resembles *N. semireticulata*, but pinnules of the former often are attached to the rachis by part of their base (i.e., not point-attached), and are characterized by broadly arching, open lateral veins (Josten 1962, Laveine 1967, Cleal and Shute 1992).

The flexuous to pseudo-reticulate venation of six forma *impar*-type pinnules support assignment to *N. semireticulata* (cf. Laveine 1967, pl. 57, figs. 5, 5a). Lateral veins on acroscopic sides of pinnules (Fig. 4.8.3; Pl. 22, Fig. 8; Pl. 23, Figs. 2, 7) typically are more broadly arching, more dense and far less flexuous than those on the basiscopic side (Fig. 4.8.3; Pl. 22, Fig. 12; Pl. 23, Figs. 3, 7), and hence can be difficult to discern from *N. obliqua*. Three large cyclopteroid-type pinnule fragments similarly have flexuous venation (Fig. 4.8.6 and 4.8.8; Pl. 18, Fig. 6; Pl. 23, Fig. 6, 8), and inclusion in this taxon is strengthened by close association of the cyclopteroid-type pinnule on the same slab with "normal" lateral and forma *impar*-type pinnules of *N. semireticulata*.

Apparently *N. semireticulata* has not yet been recorded from the Maritimes Basin, although specimens identified as *R. muensteri* from the Mabou Basin by Zodrow and Vasey (1986; eg. fig. 8, p. 216) may in fact fall within the limits of variability of *N. semireticulata* (K.-H. Josten *in* Zodrow and Vasey 1986).

Pteridosperm frond racheis

Pl. 21, Fig. 2

MATERIAL AND OCCURRENCE – Five axial fragments recovered from BB-14 preserved as devolatilized and partially decarbonized adpressions or petrifactions.

DESCRIPTION – Stems up to 8.0 cm wide, adpressed surface smooth to wrinkled, superimposed by longitudinally "fibrous" texture; wrinkles longitudinally to transversely disposed, erratically undulate, may anastomose, ca. 0.1 to 0.5 mm wide; fibers devolatilized, extremely dense, contiguous or overlapping(?), ca. 12 to 42 μm wide.

REMARKS – *Aulacopteris* is the form-genus introduced by Grand'Eury for adpressed pteridosperm racheis, while *Myeloxylon* Brongniart is the form-genus for anatomically preserved stems that represent detached petioles of *Medullosa* fronds (Taylor and Taylor 1993). *Aulacopteris* (impressions of *Myeloxylon*) is fairly easily identified by the presence of transverse and/or longitudinal, irregularly disposed wrinkles and longitudinal "fibers" that may in fact represent long, linear spines (E.L. Zodrow, personal communication, Aug. 1997).

Thin coal lenses ca. 3 to 4 mm thick found adjacent to decarbonized stem adpressions at BB-14 almost certainly represent the devolatilized remains of compressed *Aulacopteris* (*Myeloxylon*) axes.

Foliage of pteridosperm(?) affinity

Fig. 4.5.7 (p. 82); Pl. 8, Fig. 6

MATERIAL AND OCCURRENCE – Single specimen from BB-30 representing apical fragment of penultimate pinna preserved as devolatilized adpression.

DESCRIPTION – Penultimate pinna 34.5 mm long, ca. 15.4 mm wide; rachis with inconspicuous longitudinal striae, 1.81 mm wide near base, thinning distally; ultimate pinnae adjoin rachis by basiscopic side of base, acroscopic side free, arise sub-oppositely(?) and obliquely at ca. 40-50°, pinnatifid, linguaeform, apices broadly rounded, lateral margins contiguous to slightly overlapping, not exceeding 11.9 mm long, 5.0 to 6.0 mm wide, racheis repressed; pinnules broadly adjoin rachis with entirety of base, alternate, semicircular to subtriangular with obtusely rounded apices, not exceeding 3.5 mm wide.

REMARKS – The broad (i.e., unstalked) attachment of pinnatifid ultimate pinnae to the penultimate pinna rachis (Fig. 4.5.7) suggests that it may represent foliage of a callistophytalean pteridosperm, such as *Callistophyton* sp. (see Rothwell 1981). The foliage also resembles the form-genus *Mariopteris* (Boersma 1973) or *Fortopteris* (Boersma 1969). One criterion for separating these two taxa (see Boersma 1969, p. 69) is

longitudinal striations on axes of the latter, which is the case for the specimen from Blanche Brook, although this character alone does not warrant confident reference to the form-genus *Fortopteris*.

4.5 Division CONIFEROPHYTA

Order CORDAITALES

Form-genus *Cordaitanthus* Feistmantel, 1876

Cordaitanthus sp. A

Fig. 4.9.1 (p. 119); Pl. 26, Fig. 4

MATERIAL AND OCCURRENCE – Single apical(?) fragment of fructification from BB-30 preserved as devolatilized adpression; secondary axes less compressed.

DESCRIPTION – Strobilus 21.4 mm long; main axis ca. 1.1 mm wide at base, faintly longitudinally striate, bearing distichous sterile bracts; bracts sub-opposite, increasingly alternate apically, arise decurrently at 40 to 60°, linear-lanceolate, acute(?) apices, curved apically, with thin midvein, up to 11.8 mm long, ca. 360 µm wide at base, bearing single secondary axis from axils; secondary axes supported by short, thick stalk, ovate, 3.2 to 4.4 mm long, 1.9 to 2.4 mm wide, comprise helically(?) arranged vegetative scales enclosing vaulted (i.e., uncompressed) "ovulate structure"(?); structure tear drop shaped, surface smooth to granular, 1.8 to 2.3 mm long, 1.5 to 1.7 mm wide; longitudinally striate, filamentous processes arise from apices of secondary axes, ca. 3.6 to 5.8 mm long, ca. 0.4 mm wide at base, expand to ca. 0.8 to 1.0 mm wide at truncate, slightly fimbriate distal margin.

REMARKS – This specimen likely represents a female fructification referable to the form-genus *Cordaitanthus*. Ovules or seeds (now detached) might have been attached to the distal end of the long, filamentous processes or stalks that arise from swollen, secondary axes (Fig. 4.9.1; Taylor and Millay 1979; Rothwell 1988). Alternatively, the vaulted "ovulate structures" apparently enclosed by sterile scales might actually represent uncompressed, developing seeds. Filamentous processes might then be functionally equivalent and similar to stigma-like structures described from *Cordaitanthus flagellibracteatus* by Crookall (1970, p. 833).

Cordaitanthus sp. B

Fig. 4.9.2 (p. 119); Pl. 26, Fig. 1

MATERIAL AND OCCURRENCE – A single fructification fragment from BB-30 preserved as devolatilized (part) and decarbonized (counterpart) adpressions.

DESCRIPTION – Strobilus 2.5 cm long; main axis 1.8 mm wide, surface with very finely granulate, irregular, transverse elevations, bearing distichous sterile bracts; bracts opposite, nearly perpendicular at 80 to 90°, linear, acuminate(?) apices, gently curved apically, up to 3.7 mm long, 0.4 to 0.5 mm wide at base, with single fertile secondary axis nestled in axils; secondary axes sessile, cupped by sterile bract, may overlap main axis slightly, flattened, outer surface smooth, oval, 3.7 to 4.1 mm long, ca. 2.9 mm wide.

REMARKS – This specimen may represent a male fructification of cordaitean affinity. Flattened, fertile secondary axes (Fig. 4.9.2; Pl. 26, Fig. 1) may represent microsporangia,

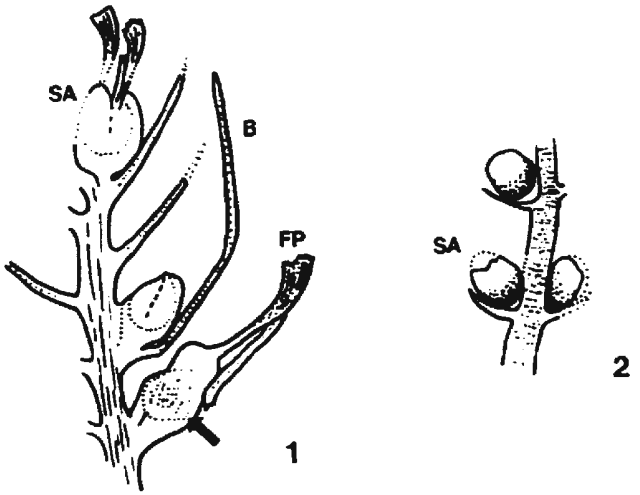

Figure 4.9. (1.) *Cordaitanthus* sp. A; secondary axes (SA) with central "ovate" body (arrow) sit atop short stalk and arise from axils of long, sterile bracts (B); filamentous processes (FP) arise from distal ends of secondary axes; BB-96-30-108, x3. (2.) *Cordaitanthus* sp. B, with secondary axes (SA) sessile and cupped by short, sterile bracts; note faint transverse markings on axis; BB-97-30-209, x2.

although pollen producing organs of *Cordaitanthus* typically are arranged as a ring of pollen sacs at the tip of vegetative scales (Delevoryas 1953; Rothwell 1988). The specimen differs from *Cordaitanthus* sp. A by the thicker, somewhat ornamented axis, much shorter sterile bracts, flattened rather than vaulted secondary axes, and lack of filamentous processes at the distal ends of secondary axes.

cf. *Cordaitanthus* sp.

Pl. 26, Fig. 10

MATERIAL AND OCCURRENCE – Single apical(?) fragment of fructification from BB-30 poorly preserved as devolatilized adpression.

DESCRIPTION – Strobilus 4.6 cm long, main axis essentially smooth, ca. 1.0 mm wide, bearing distichous sterile bracts; bracts opposite, increasingly alternate apically, nearly perpendicular but increasingly decurrent apically, linear, acuminate apices, ca. 5.4 to 7.2 mm long, extend at least 3/4 distance of secondary axis, ca. 290 µm wide near base, curve apically very slightly; secondary axes nestled in axils, sessile, flattened, outer surface smooth, oval, up to ca. 7.2 mm long, ca. 3.8 mm wide.

Cordaites Unger, 1850

Cordaites sp. cf. *C. borassifolia* (Sternberg) Unger, 1850

Fig. 4.10 (p. 123); Pl. 24, Figs. 1 to 4, 7

1970 *Cordaites borassifolius*, Crookall, pp. 807-810; text-fig. 231; pl. 153, figs. 3, 3a.

1991 *Cordaites borassifolius*, Josten, pp. 348-349; table 25 (p. 349); pl. 209, figs. 2, 3; pl. 210, fig. 2.

MATERIAL AND OCCURRENCE – Abundant leaf fragments from BB-30 preserved as decarbonized, devolatilized and "naturally macerated" volatilized adpressions; cuticles preserved. Cuticles well preserved.

DESCRIPTION – Leaves linear-lanceolate, thick, coriaceous, not exceeding 11.7 cm long (bases nor apices preserved), 6.5 to 31.4 mm wide, width increasing distally; lateral margins entire, straight, subparallel; primary veins prominent, parallel, bifurcate at extremely low angle, 94 to 150 µm wide (ave. 114 µm, n=6) near leaf centre, 0.43 to 0.81 mm distant (ave. 0.57 mm, n=36), frequency of 12.3 to 23.0/cm (ave. 16.9/cm, n=33), 32.2 and 41.7/cm near lateral margin; space between primary veins flat to vaulted,

occupied by single intermediate sclerotic strand (Pl. 24, Figs. 4, 7); strands distinct but less prominent than primary veins, 24 to 88 μm wide, centrally located, may arise from area of primary veins (Pl. 24, Fig. 7); space between primary veins very rarely occupied by intermediate sclerotic strand bordered by 2 to 4 very fine sclerotic strands in otherwise typical leaf.

REMARKS – These leaves are characterized by a single intermediate sclerotic strand between primary veins and thus compare very closely with *Cordaites borassifolia*. However, the abaxial surface of *Cordaites principalis* is also typified by a single intermediate strand (Fig. 4.10), and thus specimens may actually belong to the latter species (see p. 124 for full discussion of taphonomic effects). The rare occurrence of 2 to 4 sclerotic strands in the space between two primary veins in otherwise typical leaves does not conform to the concept of *C. borassifolia*, and supports the contention that at least some of these specimens may indeed represent *C. principalis* (i.e. most intermediate sclerotic strands not preserved.)

Cordaites sp. cf. *C. principalis* (Germar) Geinitz, 1855

Fig. 4.10 (p. 123); Pl. 24, Figs. 5, 6, 8, 9; Pl. 25, Figs. 1 to 3, 6

1938 *Cordaites principalis*, Bell, p. 103; pl. 105, fig. 1; pl. 106, fig. 1.

1961 *Cordaites principalis*, Harms and Leisman, p. 1046, pp. 1048-1057; text-fig. 2 (p. 1049); text-fig. 3 (p. 1051); pl. 125, fig. 5.

1962 *Cordaites principalis*, Bell, p. 59; pl. 55, fig. 2.

1966 *Cordaites principalis*, Bell, pl. 21, fig. 1.

1970 *Cordaites principalis*, Crookall, pp. 799-804; text-fig. 227; pl. 151, fig. 1; pl. 152, figs. 1, 1a; pl. 153, fig. 6.

1977 *Cordaites principalis*, Remy and Remy, p. 134; text-fig. 40a-c.

1991 *Cordaites principalis*, Josten, p. 348; table 25 (p. 349); pl. 209, fig. 1.

MATERIAL AND OCCURRENCE - Most abundant floral component within BBA, comprising leaf fragments from BB-14 and BB-30 preserved as decarbonized, devolatilized and "naturally macerated" volatilized adpressions; cuticles very well preserved.

DESCRIPTION – Leaves thick, coriaceous, linear-lanceolate, not exceeding 20.4 cm long (apices not preserved), down to 6.5 mm wide at base, basal attachment structure swollen and thickened (Pl. 24, Fig. 6), expanding distally up to 27.5 mm wide, lateral margins entire, straight, subparallel; primary veins prominent, parallel, bifurcate at extremely low angle (Pl. 25, Fig. 2), 140 to 230 µm wide (ave. 169 µm, n=4) near leaf centre, 0.38 to 0.94 mm distant (ave. 0.54 mm, n=80), frequency of 10.6 to 26.3/cm (ave. 20.9/cm, n=20.9) near leaf centre, 27.8 to 79.4/cm near lateral margin (Pl. 24, Fig. 5; Pl. 25, Fig. 1), frequency often inversely proportional to leaf width; space between primary veins flat to vaulted (Pl. 24, Figs. 8, 9), occupied by 0 to 6 (usually 3 to 5) intermediate sclerotic strands; strands 41 to 90µm wide, 57 to 160 µm distant, central strand on abaxial cuticle often thicker and comparatively prominent (Pl. 24, Fig. 8, 9; Pl. 25, Fig. 6).

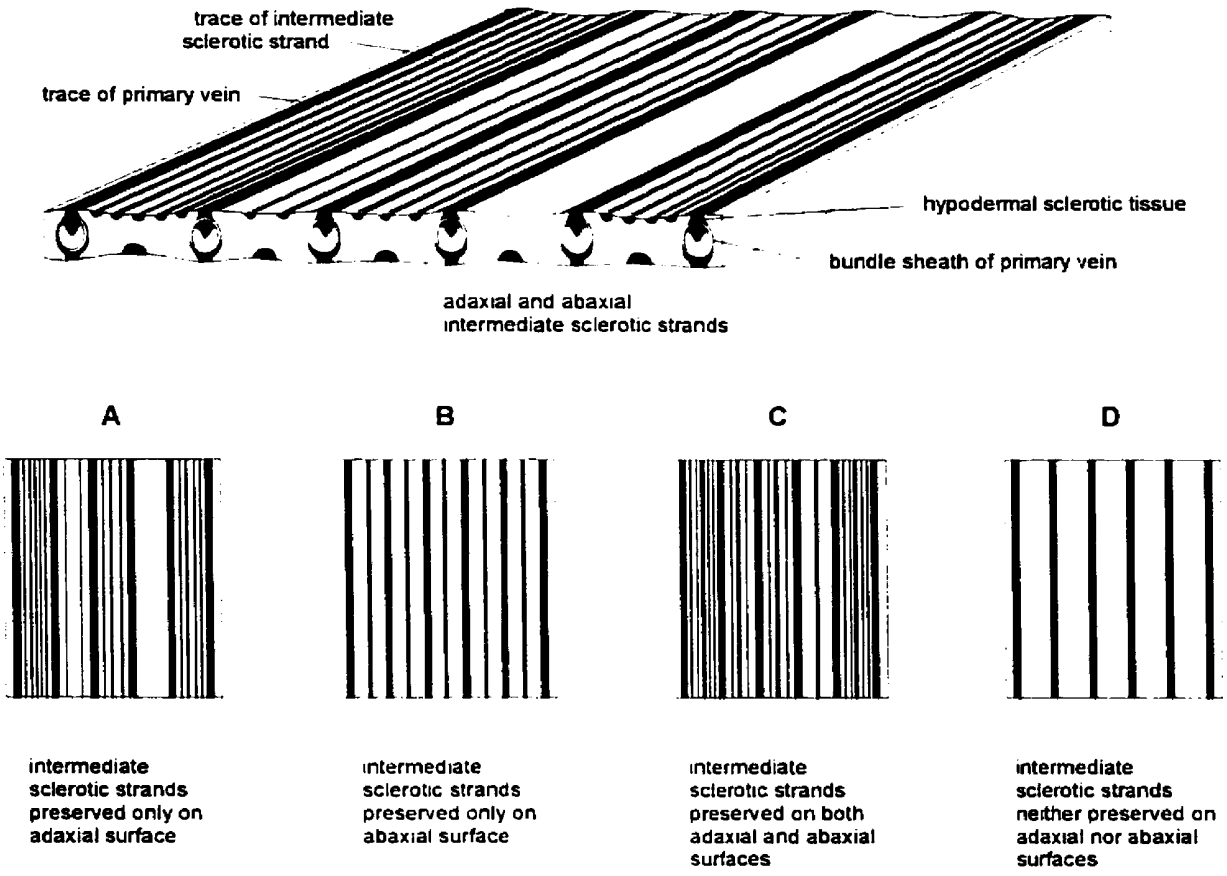

Figure 4.10. Hypothetical schematic cross-section of *Cordaites principalis* leaf (after Harms and Leisman 1961) demonstrating complications in accurate identification of adpressed cordaitean foliage resulting from taphonomic biases introduced by differential preservation of intermediate sclerotic strands. Although scenarios A and C result in fossils that conform to the *C. principalis* concept for adpressed foliage, scenario B conforms more closely to the *C. borassifolia* concept. Likewise, scenario D results in a fossil conforming to the *C. palmaeformis* concept for adpressed leaves (see Crookall 1970).

REMARKS – Specific determination of adpressed cordaitean foliage relies heavily on the size and shape of leaves, and distribution and relationship between primary veins and intermediate sclerotic strands. Unfortunately, foliar polymorphism and taphonomic factors often confound accurate determination. As Harms and Leisman (1961) pointed out, leaf form and "ribbing" of *Cordaites* vary depending on which part and side (abaxial or adaxial) of the leaf is preserved (and size and age of the foliage), while preservation of intermediate strands is too strongly controlled by conditions of fossilization for them to be dependable taxonomic indicators.

The material conforms most closely with *Cordaites principalis*, a species with vein frequencies of 11 to 26/cm (cf. 13 to 28/cm, Harms and Leisman 1961, p. 1050), and variations of 0 to 6 intermediate sclerotic strands between primary veins (cf. 0 to 5, Harms and Leisman 1961, p. 1050; cf. 1 to 6 Crookall 1970, p. 801). However, as Harms and Leisman (1961, text-fig. 3, p. 1051) demonstrated, only the adaxial side of the leaf has a variable number of strands, while the abaxial surface is characterized by a single prominent sclerotic strand (Fig. 4.10). Accordingly, the presence of a thicker, more prominent, central intermediate sclerotic strand between less prominent strands suggests superposition of adaxial and abaxial cuticles (Fig. 4.10; Pl. 24, Figs. 8, 9; Pl. 25, Fig. 6). Suppose though that only the abaxial leaf surface was preserved – the material could easily be misidentified as *C. borassifolia* (Fig. 4.10; cf. Pl. 24, Figs. 4, 7). Alternatively, if neither abaxial nor adaxial sclerotic strands were preserved, spaces between primary veins would be empty, and adpressions would be morphologically identical to *Cordaites* sp. A (Fig. 4.10; cf. Pl. 24, Fig. 4). It is apparent then that several vein/strand patterns are

possible for *C. principalis* depending on the degree of preservation and whether abaxial or adaxial (or both) surfaces are preserved.

Cordaites sp. A

Fig. 4.10 (p. 123); Pl. 25, Figs. 4, 5, 8

MATERIAL AND OCCURRENCE – Four leaf fragments from BB-30 preserved as devolatilized or "naturally macerated" volatilized adpressions.

DESCRIPTION – Leaves linear-lanceolate, thick, coriaceous, 8.2 to 11.9 mm wide; lateral margins entire, straight, subparallel; primary veins prominent, parallel, 100 to 160 µm wide, 0.25 to 0.62 mm distant (ave. 0.47 mm, n=16), vein frequency 16.0 to 40.0/cm (ave. 22.5/cm, n=16), frequency greatest near lateral margins; space between primary veins flat to vaulted, characteristically absent of intermediate sclerotic strands (Pl. 25, Fig. 4), single strand rarely preserved in otherwise typical leaf.

REMARKS – The absence of intermediate sclerotic strands between primary veins bears resemblance to *Cordaites palmaeformis*, which is characterized by broad (up to 10 cm) leaves with acutely or bluntly pointed apices (see Crookall 1970, p. 812, pl. 154, fig. 1). Unfortunately, no apices are preserved in the BBA to aid specific identification.

Intermediate sclerotic strands between primary veins initially may have existed but simply were not preserved (see full discussion, p. 124, Fig. 4.10). The rare occurrence of a single intermediate strand between primary veins (cf. *C. borassifolia* or abaxial surfaces of *C. principalis*) in otherwise typical leaves supports the contention that

specimens assigned to *Cordaites*. sp. A may simply represent differentially preserved leaves of one of these taxa.

Cordaites sp. B

Pl. 25, Fig. 7; Pl. 26, Figs. 2, 3

MATERIAL AND OCCURRENCE – Several leaf fragments from BB-25 and BB-34c preserved as devolatilized adpressions; leaves from BB-34c mechanically degraded and split. Cuticles poor to moderately well preserved.

DESCRIPTION – Leaves thick, coriaceous, surfaces smooth, up to 15.2 cm long (bases nor apices preserved), 17.5 to 45.0 mm wide; lateral margins entire, straight, subparallel, acutely rounded in transverse section; smoothness of leaf surface hinders differentiation of primary veins from intermediate sclerotic strands; "ribbing" parallel, irregularly spaced, 21 to 94 μm wide, 56 to 153 μm distant, "rib" frequency 65.4 to 178.6/cm; prominent ribs or furrows (trace of primary veins?) (Pl. 25, Fig. 7) superimposed on surface of some leaves, equidistant, ca. 0.35 to 0.47 mm apart, vein frequency 18.5 to 28.6/cm.

REMARKS – This taxon is typified by leaves with comparatively smooth surfaces (ribbing often nearly invisible without magnification) and irregular "ribbing", which serves to separate specimens from other *Cordaites* in the BBA. Leaves compare quite well with *Cordaites crassus*, a species with unusually smooth leaf surfaces; variable,

irregularly spaced ribbing; and a vein frequency of 15 to 40/cm (Harms and Leisman 1961).

Form-genus *Dadoxylon* Endlicher, 1847

***Dadoxylon* sp.**

Fig. 4.11 (p. 128); Pl. 26, Fig. 11

MATERIAL AND OCCURRENCE – Abundant axial fragments preserved as volatilized petrifactions collected from channel lag and point bar sublithofacies at numerous localities. Description based on four thin sections from three petrifactions made in transverse plane (i.e., perpendicular to growth axis of tree).

DESCRIPTION – Secondary xylem (wood) pycnoxylic, comprising axial system of axially elongated tracheids, and ray system of radially elongated vascular rays (Fig. 4.11); tracheids arranged in ca. 1 to 7 (ave. 3, n=35) radially, irregularly disposed rows between vascular rays, circular to equidimensional (before compaction) in transverse plane, 27 to 70 μm in diameter (ave. 47 μm, n = 62), longitudinal dimensions indeterminate; cell walls only 1.2 to 2.8 μm thick (ave. 1.9 μm, n = 22); secondary cell wall thickenings developed on radial walls, form closely spaced, alternately(?) disposed, biseriate rows of dome shaped bordered pits that project into cell cavity (Fig. 4.11; Pl 26, Fig. 11); vascular rays uniseriate, 10 to 48 μm wide (ave. 25 μm, n=35) in transverse section, representing thickness of single vascular ray cell.

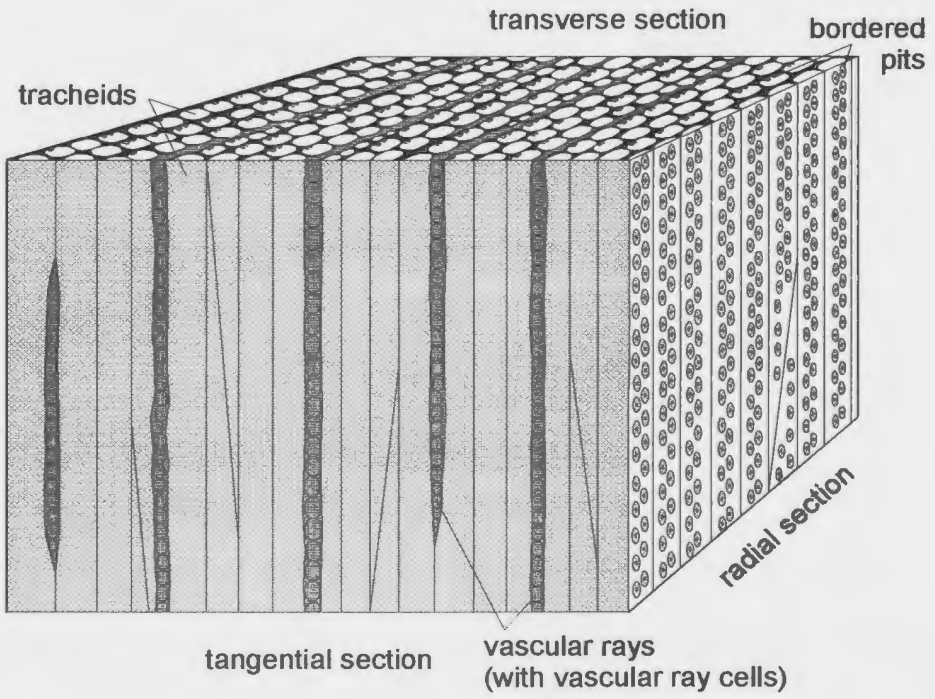

Figure 4.11. Schematic reconstruction of secondary xylem (wood) of *Dadoxylon* sp. (presumably of cordaitean affinity) recovered from Blanche Brook.

REMARKS – This wood came from large volatilized petrifactions interpreted to be the remnants of large forest-forming trees of cordaitean affinity (*Eu-Cordaites sensu* Grand'Eury 1877). In order to correctly refer anatomically preserved stem petrifactions of cordaitean affinity to established form genera (eg. *Mesoxylon*, *Cordaixylon* or *Pennsylvanioxylon*), axes must be sufficiently well preserved that relationships within and between primary and secondary phloem and xylem can be observed (Rothwell and Warner 1984; Costanza 1985; Trivett and Rothwell 1985, 1988). However, when fragments only constitute dense, pycnoxylic wood (secondary xylem), as is the case with material described here, specimens are better referred to the Paleozoic wood form-genus *Dadoxylon* (Vogellehner 1964; Taylor and Taylor 1993).

The presence of circular, alternately arranged bordered pits on radial walls of tracheids (Fig. 4.11; Pl. 26, Fig. 11) helps to differentiate *Dadoxylon* from wood of the nearly indistiquishable *Araucarioxylon* type, which belongs to Mesozoic conifers and have cell walls with bordered pits that either are uniseriate and flattened or polyseriate and polygonal (Stewart and Rothwell 1993).

Form-genus *Samaropsis* Göppert, 1864

***Samaropsis* spp.**

Pl. 26, Figs. 5, 6, 9

MATERIAL AND OCCURRENCE – Five isolated seeds from BB-30 preserved as decarbonized or devolatilized adpressions.

DESCRIPTION – Seeds platyspermic, comprise central nucellus surrounded by narrow, membranous wing (sarcotesta), nearly circular, outer surface smooth or reticulate(?), bases flattened, apices slightly pointed, 6.6 to 7.2 mm long, 6.0 to 7.6 mm wide, L:W ratio 0.95 to 1.15; micropyles (Pl. 26, Fig. 5) ca. 26 μm wide; central nucellus nearly circular, surface smooth to finely granulate, 4.1 to 5.6 mm in diameter, perhaps slightly wider than long.

REMARKS – All specimens possess a narrow, membranous wing or sarcotesta (Pl. 26, Figs. 5, 6, 9) that characterizes the (adpressed) cordaitean ovule Form-genus *Samaropsis* (Rothwell 1988). Specific differentiation of this taxon is difficult because: (i) the size and shape of a specimen is controlled by maturity of the seed; and (ii) the diagnostic membranous wing may be very narrow or become detached, resulting in inaccurate inclusion of the specimen in the form-genus *Cordaicarpus* (Crookall 1976, p. 909). One specimen (Pl. 26, Fig. 9) has a reticulate(?) textured surface, indicating that more than one seed species may be included in this designation.

Axis of cordaitean(?) affinity

Pl. 26, Figs. 7, 8

MATERIAL AND OCCURRENCE – Single stem fragment from BB-25 preserved as decarbonized adpression.

DESCRIPTION – Axis 7.1 cm wide, longitudinally wrinkled (Pl. 26, Fig. 7), superimposed upon which are helically arranged rows of elevations or swellings (Pl. 26,

fig. 8); rows 5.2 to 5.6 mm apart; swellings lenticular, ca. 5.2 to 5.7 mm apart within single row, 3.6 to 4.9 mm long, 0.9 to 1.1 mm wide, broadest in middle, tapering laterally.

REMARKS – This axis imprint is of unknown affinity, although the small, helically arranged elevations superficially resemble leaf scars found on cordaitean stems (eg. Crookall 1970, pl. 157, figs. 3, 4; Rothwell 1988, fig. 6.2c, p. 276).

PLATE 1

Figs. 1 to 6. – cf. *Cyperites bicarinatus* Lindley and Hutton, 1833

1. Devolatilized adpressions of lepidodendrid(?) origin; BB-96-30-157, x1
2. Abaxial surface; devolatilized adpression, BB-96-30-132, x2
3. Carina on abaxial surface; decarbonized adpression, BB-94-30-33, x2
4. Carina on abaxial surface; decarbonized adpression, BB-96-30-123a, x2
5. Median furrow and longitudinal grooves on adaxial surface; of sigillarian(?) origin; devolatilized adpression, BB-96-32-25, x1
6. Enlargement of Fig. 4, x2

Figs. 7 to 9, 11, 12, 14. – *Lepidostrobophyllum alatum* Boulter, 1968

7. Adaxial surface with midrib; decarbonized adpression, BB-30-96-69, x2
8. Transverse view of cone fragment; devolatilized adpression, BB-96-F-2, x2
9. Slight constriction ca. 1/4 way up blade of sporophyll; devolatilized adpression, BB-96-30-121, x2.
11. Imprint of hair-like alations rimming pedicel of sporophyll (arrow); devolatilized adpression, BB-94-30-10, x8
12. Slight constriction ca. 1/4 way up blade of sporophyll; devolatilized adpression, BB-96-30-147, x2
14. Lateral view; devolatilized adpression, BB-96-30-111, x2

Figs. 10, 13, 15, 16. – *Lepidostrobophyllum triangulare* (Zeiller) Bell, 1938

10. Compare with sporophyll of *L. alatum* (la); devolatilized adpressions, BB-96-30-69, x1
13. Transverse view of cone fragment; devolatilized adpression, BB-96-30-156, x2
15. Devolatilized adpression, BB-96-30-134, x2
16. Adaxial surface; devolatilized adpression, BB-96-30-70, x2

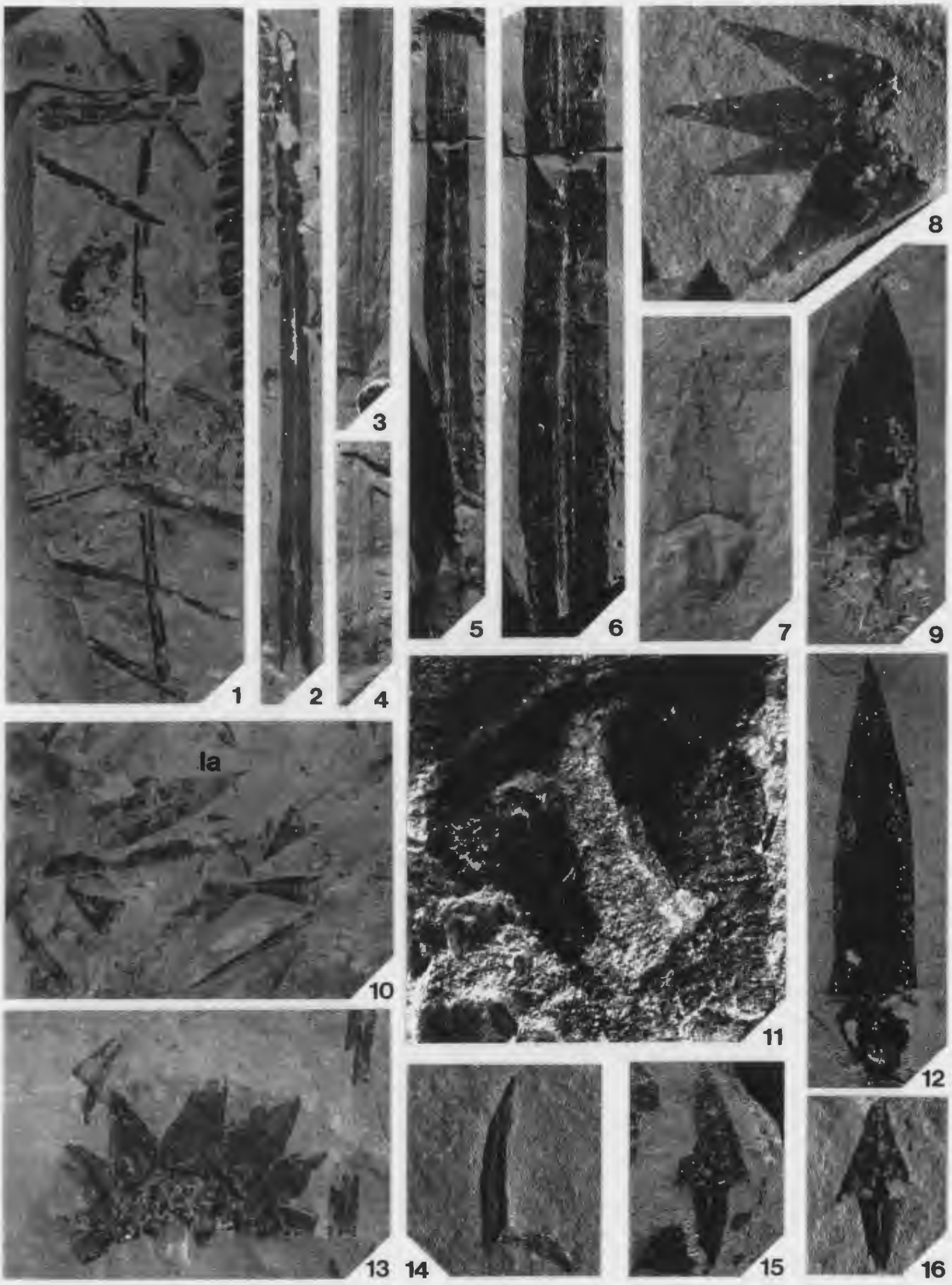
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PLATE 2

Figs. 1 to 9. – "*Lepidodendron*" sp. cf. "*L.*" *bretonense* Bell, 1962

1. Interior bark surface; decarbonized adpression, BB-96-30-123a, x1
2. Exterior bark surface; decarbonized adpression, BB-94-30-6, x1
3. Enlargement of Fig. 2; keel (k) in lower field of immature cushions; x2
4. Latex peel of immature cushions; flat, triangular surface occupies upper corner of upper field (arrow); leaf scars inflated and inclined downward; BB-96-30-123a, x2
5. Immature cushions; distal dichotomy; devolatilized adpression, BB-96-30-141, x1
6. Enlargement of Fig. 1; irregular longitudinal striations on immature cushions; x2
7. Mature cushions separated by wrinkled interareas (arrow); decarbonized adpression, BB-96-30-132, x2
8. Mature cushions with keel in lower field; decarbonized adpression, BB-96-30-132, x2
9. Enlargement of Fig. 1; leaf scars with cicatricules, central vascular trace flanked by foliar parichnos traces; x8

Figs. 10, 11. – Isolated lycopsid sporangia

10. Devolatilized adpression, BB-96-25-6, x2
11. Devolatilized adpression, BB-96-25-3, x2

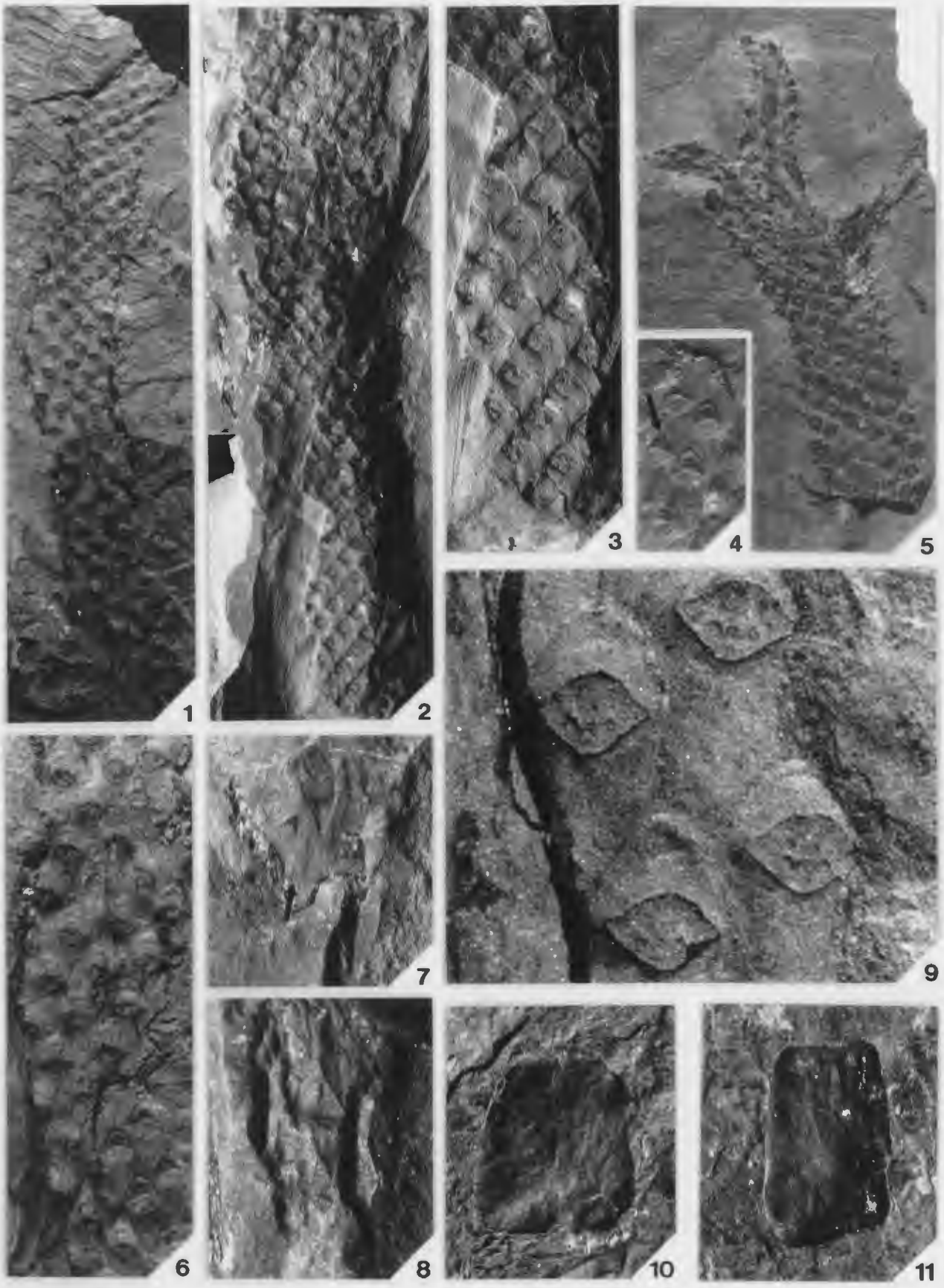
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PLATE 3

Figs. 1, 2. – *Stigmaria ficoides* (Sternberg) Brongniart, 1822

1. Interior(?) rhizophore surface with low relief longitudinal ribs and attached lateral appendages; partially decarbonized adpression, BB-94-30-10, x1
2. Dichotomy in lateral appendage; devolatilized adpression, BB-96-14-2, x1

Fig. 3 – Lycopsid cone

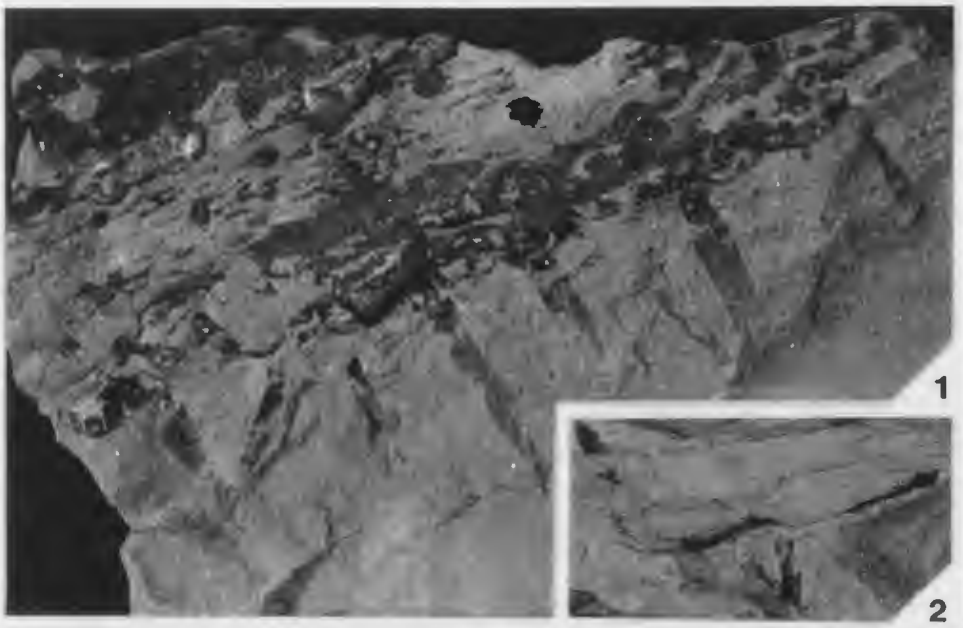
3. Radial section; partially decarbonized adpression, BB-96-32-2, x1

Figs. 4, 5 – *Sigillaria* sp.

4. Partially decorticated exterior bark surface; partially decarbonized adpression, BB-96-32-16, x1
5. Enlargement of Fig. 4; slightly inflated leaf scars with central vascular trace flanked by foliar parichnos traces (arrow); x2

Figs. 6, 7 – *Sigillariostrobus rhombibracteatus* Kidston, 1897

6. Devolatilized adpression, BB-96-32-14, x3
7. Enlargement of Fig. 6; ciliate margin (arrow); x12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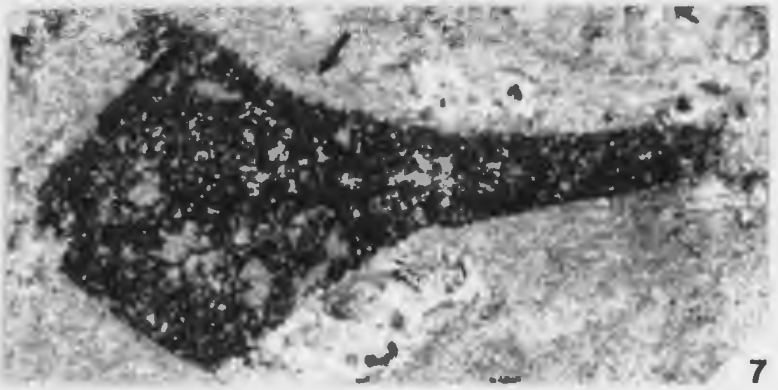
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PLATE 4

Figs. 1 to 9. – *Sphenophyllum emarginatum* (Brongniart) Brongniart, 1828

1. Large branch bearing linear leaflets and two twigs from adjacent nodes; devolatilized adpression, BB-96-30-102, x1
2. Twig with leaflets; devolatilized adpression, BB-96-30-104, x2
3. Enlargement of Fig.8; uncate arista (hook) at terminus of linear leaflet of main axis(?); x10
4. Whorl comprising 10 leaflets; partially decarbonized adpression, BB-94-30-39, x1.5
5. Main axis with linear, undivided leaflets; partially decarbonized adpression, BB-96-30-111, x2
6. Enlargement of Fig. 8; leaflets on twig becoming more cuneate and with corresponding increase in number of teeth at distal margin (i.e. increasingly more mature; 1, 2, 3, 4 = number of teeth); x2
7. Main axis; partially decarbonized adpression, BB-96-30-125, x0.8
8. Main axis bearing two twigs from same node; devolatilized adpression, BB-94-30-31, x1
9. Enlargement of Fig. 8; large branch (lb) bearing bipartite leaflet (bl); undivided linear leaflets (ul) arising from node of main axis; devolatilized adpression, x2


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PLATE 5

Figs. 1 to 7. – *Sphenophyllum emarginatum* (Brongniart) Brongniart, 1828

1. Mature leaflets on twigs; "naturally macerated" volatilized adpressions, BB-94-30-22, x2
2. Enlargement of Fig. 1; single vein terminates in each semicircular tooth; midcleft (mc); secondary cleft (sc); x10
3. Twig with leaflets; devolatilized adpression, BB-94-30-7, x2
4. Twig with leaflets; devolatilized adpression, BB-96-30-152, x2
5. Enlargement of Fig. 4; hairs (arrows) on axis; x10
6. Mature leaflets; devolatilized adpression, BB-94-30-44, x2
7. Main axis and immature twig; devolatilized adpression, BB-94-30-49, x1


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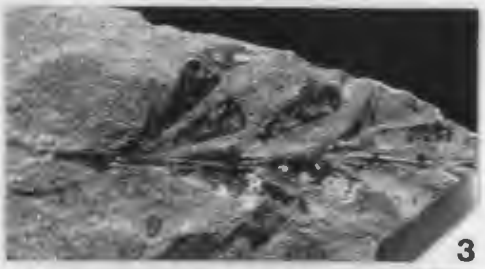


PLATE 6

Figs. 1 to 4. – *Sphenophyllum* sp. cf. *zwickaviense* Storch, 1966

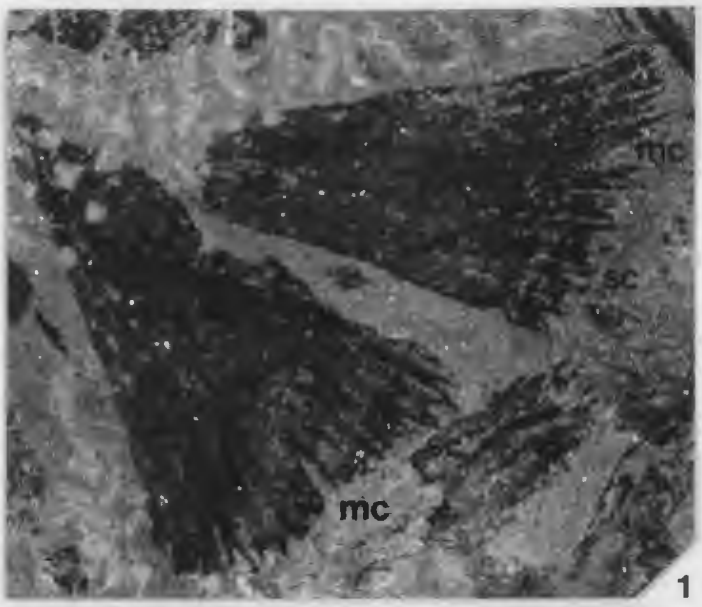
1. Enlargement of Fig. 3; sharp point terminates acute-triangular teeth; leaflets either symmetrical (lower) or asymmetrical (upper) depending on position of midcleft (mc); secondary cleft (sc); x5
2. Teeth on distal leaflet margin; "naturally macerated" volatilized adpressions, BB-94-30-73, x2
3. "Naturally macerated" volatilized adpression, BB-94-30-73, x2
4. Asymmetrical leaflet; midcleft (mc); secondary cleft (sc); "naturally macerated" devolatilized adpression, BB-96-30-133, x2

Figs. 5, 7 to 10. – *Annularia sphenophylloides* (Zenker) Gutbier, 1837

5. "Naturally macerated" volatilized adpression, BB-30-96-160, x2
7. Whorls of leaflets arising from inconspicuous, circular sheath (s); terminal expansion (te) at leaflet terminus; "naturally macerated" volatilized adpression, BB-96-30-160, x2
8. Branching axis; leaflets with single vein ending as terminal expansion at mucronate tip (arrow); BB-96-30-173, x1.5
9. Enlargement of Fig. 10; mucronate tips on leaflets; x8
10. Branching axis; sheaths (s) considerably larger than average (cf. Fig. 7); devolatilized adpression, BB-96-30-73, x1

Fig. 6. – *Pinnularia capillacea* Lindley and Hutton, 1834

10. Devolatilized adpression, BB-96-30-89, x2



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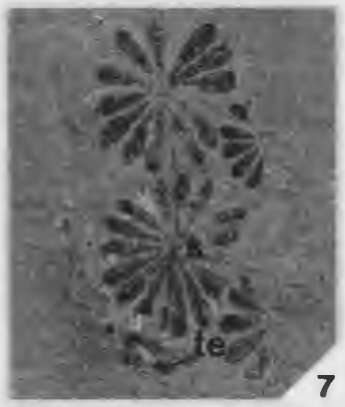

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PLATE 7

Fig. 1. – *Annularia sphenophylloides* (Zenker) Gutbier, 1837

1. Branching axes; devolatilized and "naturally macerated" volatilized adpressions, BB-96-30-173, x1

Figs. 2, 4. – *Asterophyllites equisetiformis* (Sternberg) Brongniart, 1828

2. Devolatilized adpression, BB-30-96-145, x2
4. Devolatilized adpression, BB-30-96-92, x2

Figs. 3, 5, 9. – cf. *Asterophyllites* sp.

3. Enlargement of Fig. 9; bud-like structure (arrow) atop tertiary axis; x6
5. Enlargement of Fig. 9; stiff leaflets in whorl cupping tertiary axis which is terminated by bud-like structure; x10
9. Primary (p), secondary (s) and tertiary (t) branches, culminating in bud-like structures; devolatilized adpressions, BB-96-19-1, x2

Fig. 6. – *Annularia stellata* (Schlotheim) Wood, 1861

6. Whorls comprising leaflets ending in sharp, mucronate tips (m); devolatilized adpression, BB-96-30-172, x1

Fig. 7. – *Calamites* sp. B

7. Enlargement of Pl. 8, fig. 4; narrow ribs pass directly through node (cf. Fig. 8); decarbonized adpression, BB-96-25-39, x2

Fig. 8. – *Calamites* sp. A

8. Enlargement of Pl. 8, fig. 3; ribs alternate at node (cf. Fig. 7); imprints of infranodal canals (ic); decarbonized adpression, BB-96-30-109, x2

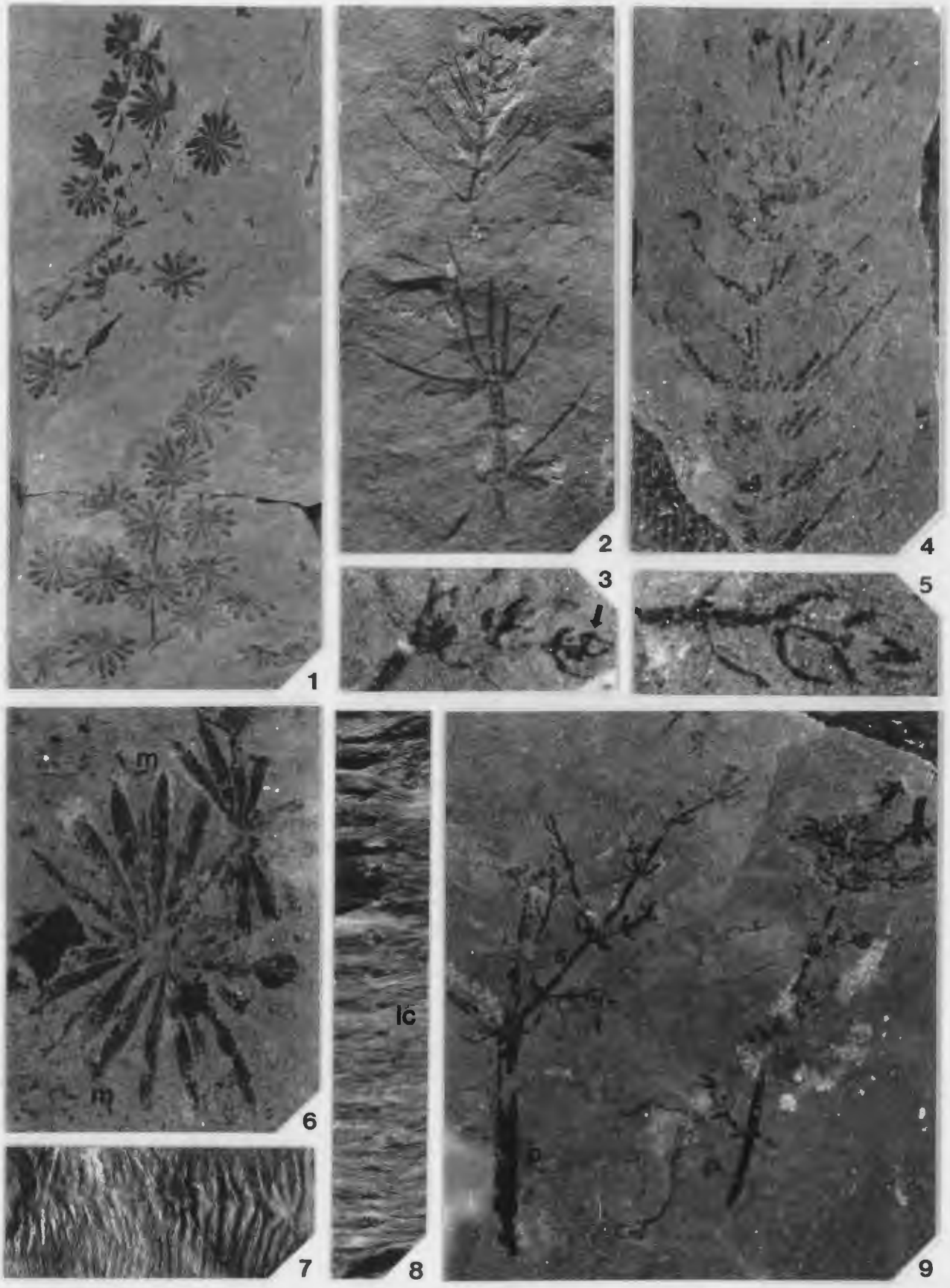
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PLATE 8

Figs. 1, 2. – cf. *Myriophyllites gracilis* Artis, 1825

1. "Naturally macerated" volatilized adpression (vascular strands coalified), BB-96-29-1, x0.8
2. Enlargement of Fig. 1; longitudinal vascular strands (vs) parallel to root axes terminate as hair-like rootlets (r); x2

Fig. 3. – *Calamites* sp. A

3. Decarbonized adpression, BB-96-30-109, x1

Fig. 4. – *Calamites* sp. B

4. Decarbonized adpression, BB-96-25-39, x1

Fig. 5. – *Paracalamostachys* sp. Weiss, 1884

5. Devolatilized adpressions, BB-96-30-73, x2

Fig. 6. – Foliage of pteridosperm(?) affinity

6. Ultimate pinna adjoins rachis by basiscopic side (b) of base, acroscopic side (a) free; devolatilized adpression, BB-96-30-126, x2

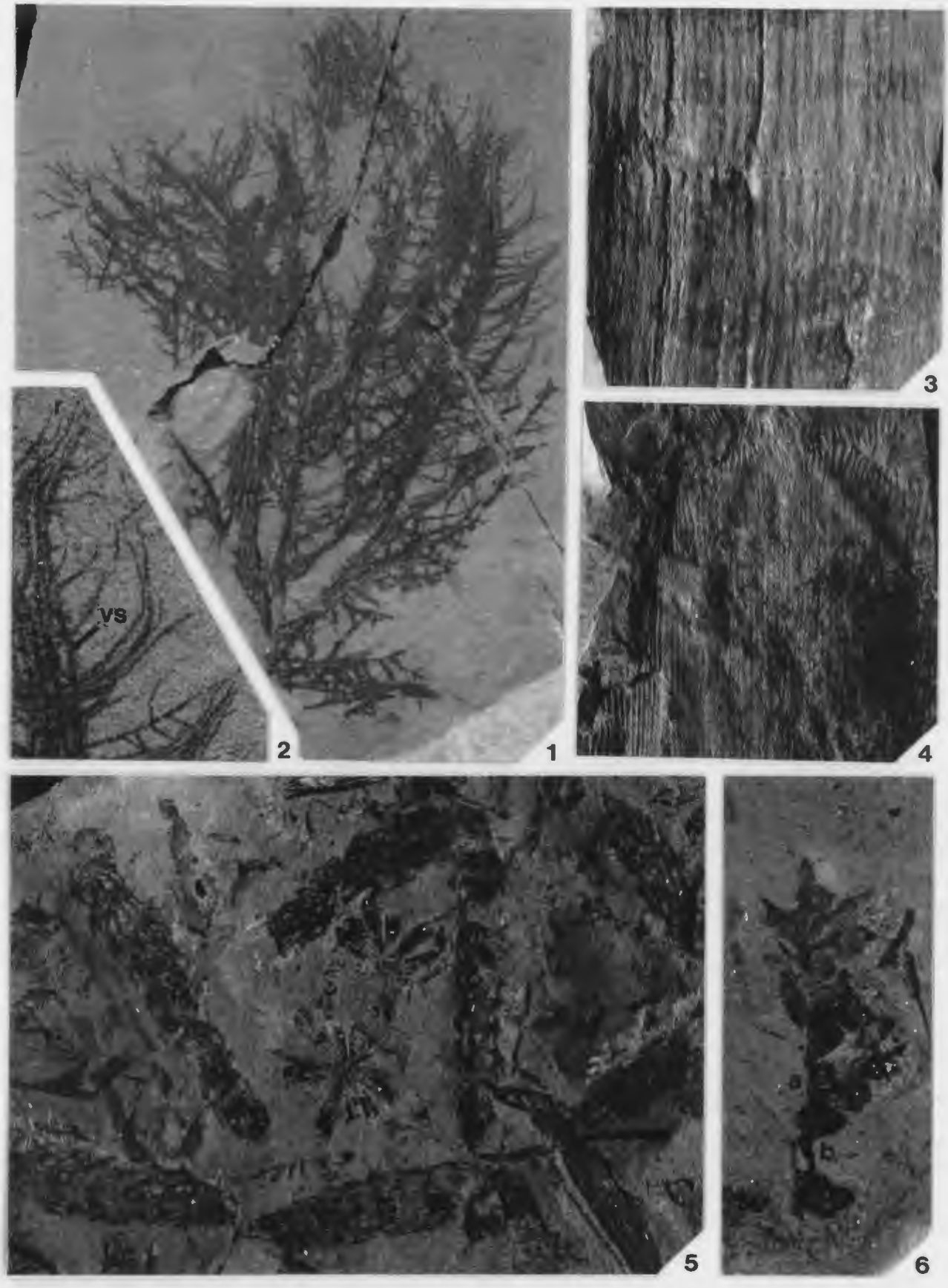
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PLATE 9

Figs. 1 to 7. – *Lobatopteris* sp. A

1. Distal penultimate pinna with decurrent pinnules arising from ultimate pinnae; devolatilized adpression, BB-94-30-42, x1.5
2. Distal penultimate pinna; "naturally macerated" volatilized adpression, BB-97-30-242, x1.5
3. Distal ultimate pinna with decurrent pinnules and midveins; acroscopic side of pinnules markedly incised (arrow); "naturally macerated" volatilized adpression, BB-96-30-70, x2
4. Distal ultimate pinna; "naturally macerated" volatilized adpression, BB-97-30-253, x1.5
5. Distal penultimate pinna; devolatilized adpression, BB-94-30-33, x1
6. Proximal ultimate pinna with decurrent, pinnatifid pinnules; devolatilized adpression, BB-94-30-22, x1.5
7. Distal penultimate pinna with blunt, subtriangular apex; devolatilized adpression, BB-30-96-111, x1.5

Fig. 8. – *Aphlebia* sp. Presl, 1838

8. "Naturally macerated" volatilized adpression, BB-96-30-89, x2

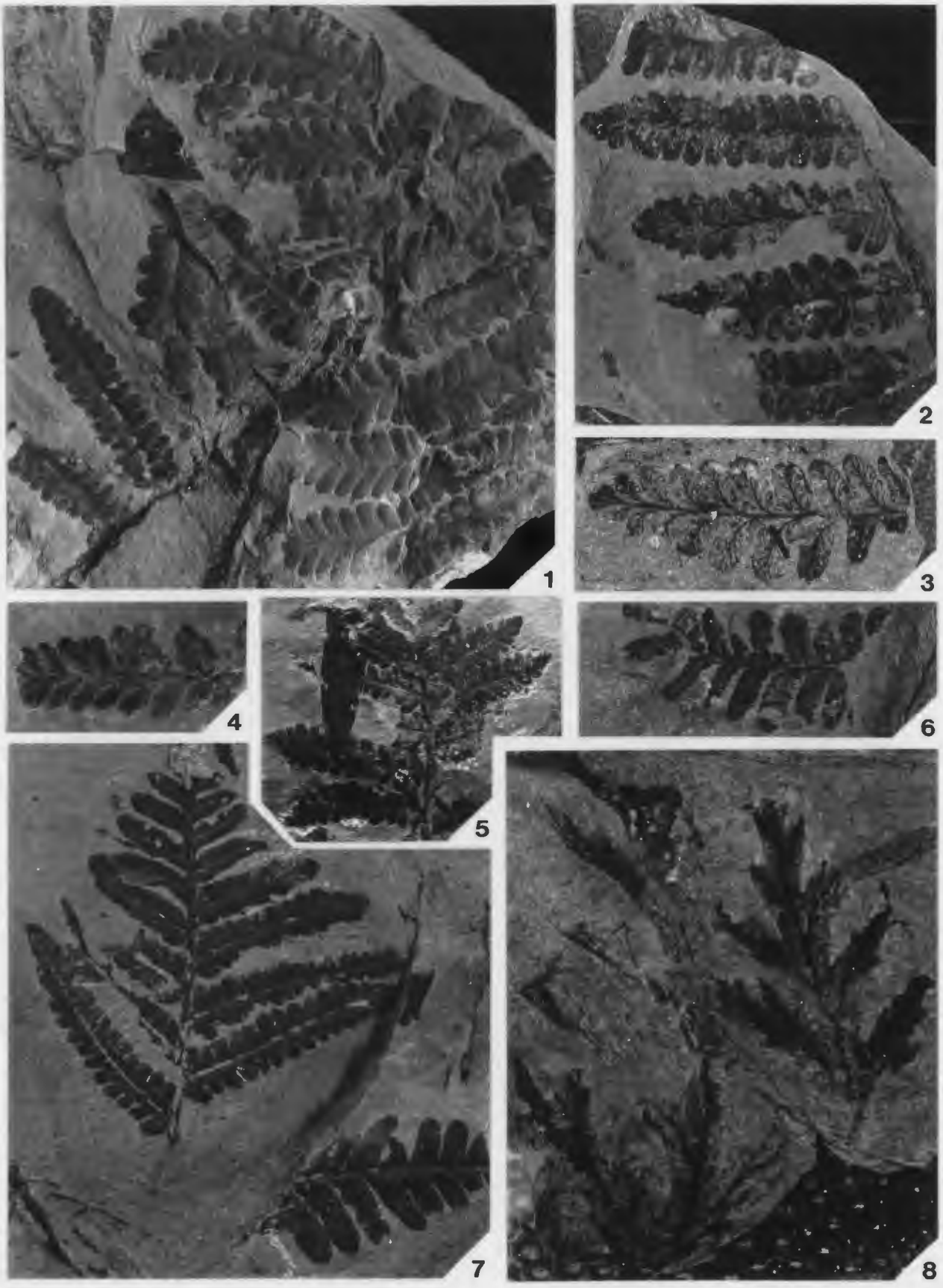
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PLATE 10

Fig. 1. – *Lobatopteris* sp. A

1. Elongate-triangular proximal and distal penultimate pinnae – note close similarity between uppermost ultimate pinnae on proximal penultimate pinna (mpp) and lowermost ultimate pinnae on distal penultimate pinna (ipp) (cf. Pl. 11, Fig. 4), demonstrating morphological gradation between and suggesting affinity of the frond fragments; lowermost ultimate pinnae of proximal penultimate pinna comprise pinnatifid pinnules (p); devolatilized adpression, BB-96-30-177, x0.7

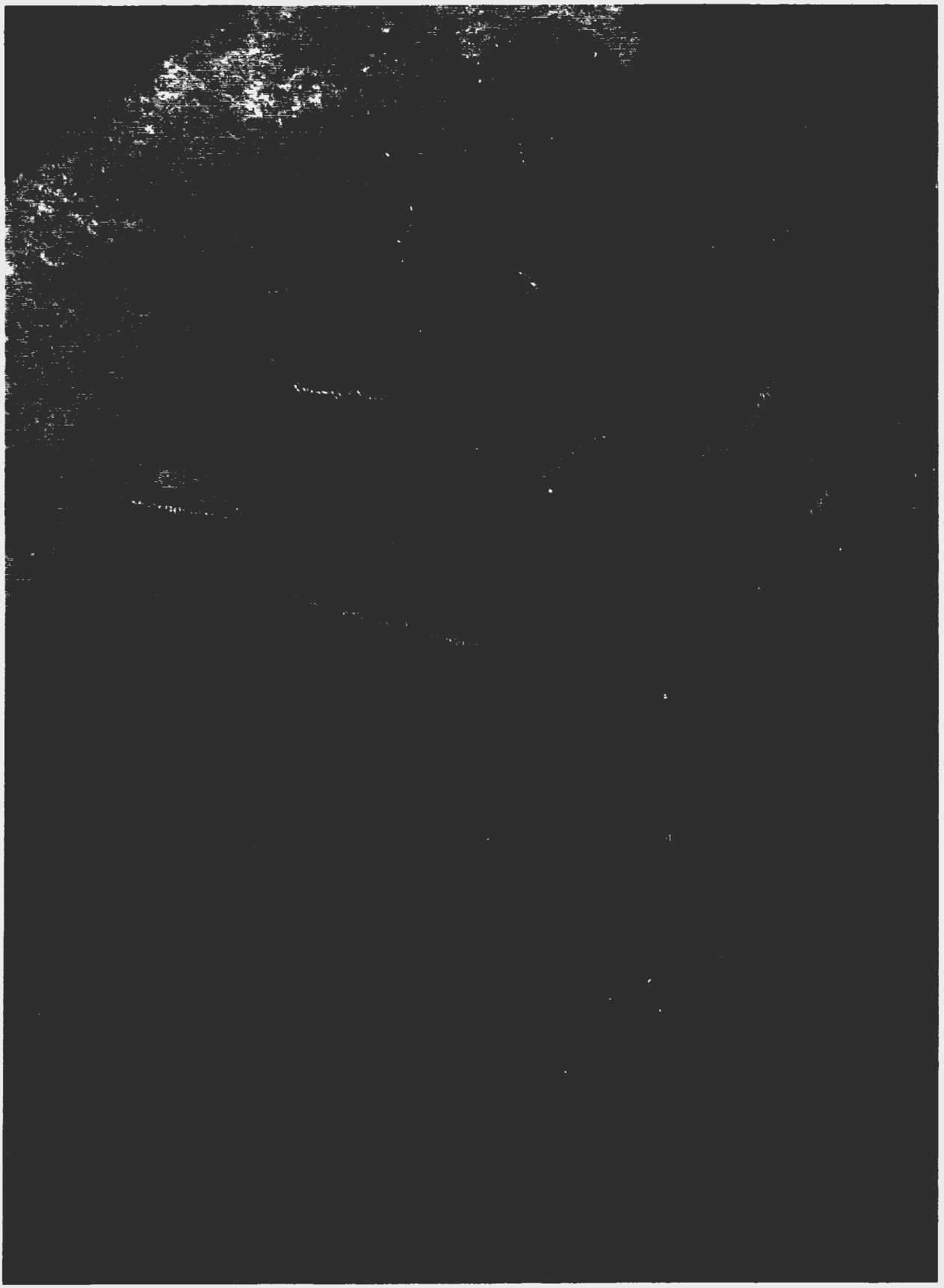

PLATE 11

Figs. 1 to 5. – *Lobatopteris* sp. A

1. Distal penultimate pinnae; devolatilized adpressions, BB-96-F-1, x1
2. Proximal ultimate pinna; acroscopic side of pinnules markedly incised; devolatilized adpression, BB-97-30-229, x1
3. Acutely rounded, elongate-triangular apex of distal penultimate pinna; note morphological similarity between entire and pinnatifid pinnules with those pinnules comprising proximal ultimate pinnae [pinnatifid pinnules (cf. Fig. 5; Pl. 12, Fig. 3; Pl. 13, Fig. 2), entire pinnules (cf. Fig. 2, Pl. 10, Fig. 1; Pl. 12, Figs. 1, 2, 4, 5; Pl. 13, Fig. 1)], suggesting affinity of distal and proximal frond elements; acroscopic side of pinnules markedly incised; devolatilized adpression, BB-96-30-JC-1, x2
4. Enlargement of Pl. 10, Fig. 1; acutely rounded, elongate-triangular apex of distal penultimate pinna; partially "naturally macerated" volatilized adpression, BB-96-30-177, x1.5
5. Proximal ultimate pinna comprising pinnatifid pinnules; note venation (arrow) (cf. Fig. 4.5.3); partially "naturally macerated" volatilized adpression, BB-97-30-245, x2

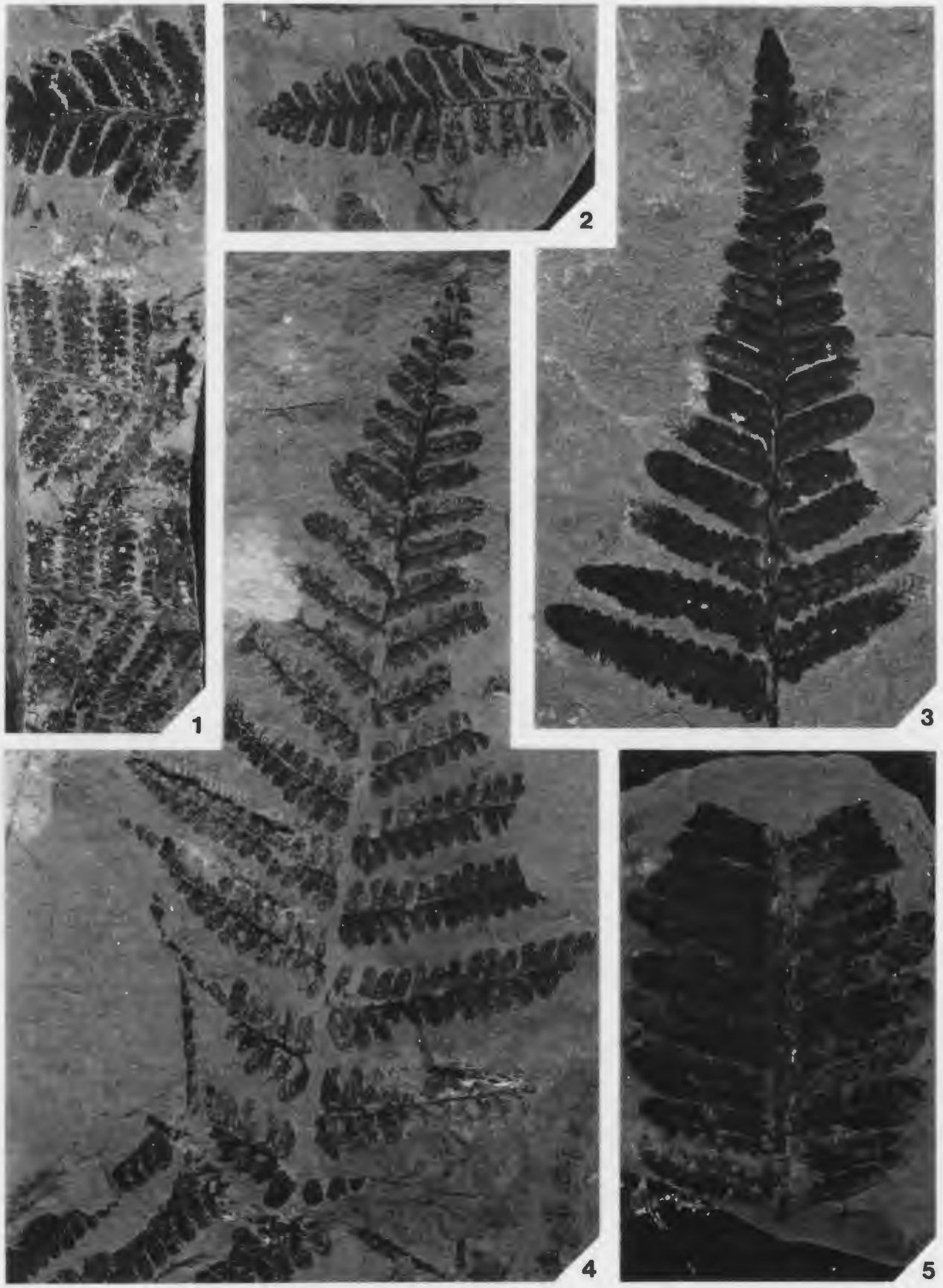
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PLATE 12

Figs. 1 to 5. – *Lobatopteris* sp. A

1. Proximal penultimate pinna; "naturally macerated" volatilized adpression, BB-96-30-170, x0.7
2. Enlargement of Fig. 1; decurrent midveins and pinnules throughout length of ultimate pinnae; x2
3. Proximal ultimate pinnae comprising pinnatifid pinnules; punctae (arrow) on rachis of penultimate pinna; decarbonized adpression, BB-94-30-33, x1
4. Proximal ultimate pinna; midveins markedly decurrent (arrow); acuminate hairs arising from pinna rachis and pinnule midveins; decarbonized adpression, BB-94-30-51, x2
5. Obtusely rounded apex of proximal ultimate pinna; devolatilized adpression, BB-96-30-158, x1.5


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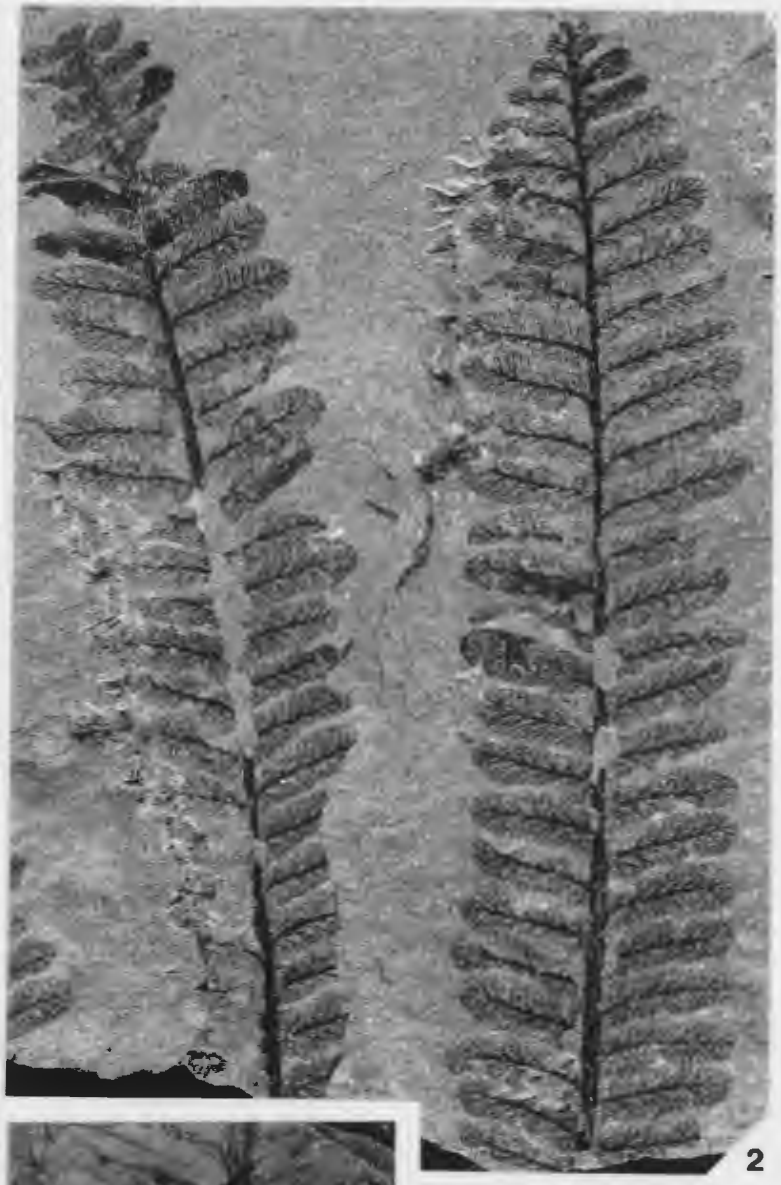
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PLATE 13

Figs. 1 to 4. – *Lobatopteris* sp. A

1. Proximal penultimate pinna; "naturally macerated" volatilized adpression, BB-96-30-177, x1
2. Proximal ultimate pinna comprising pinnatifid pinnules; note similarity between these pinnules and pinnatifid pinnules near apices of distal penultimate pinnae (cf. Pl. 9, Fig. 7; Pl. 11, Figs. 1, 3, 4); devolatilized adpression, BB-96-30-177, x1
3. Proximal ultimate pinna; acroscopic side of pinnules markedly incised; devolatilized adpression, BB-96-30-158, x1.5
4. Proximal ultimate pinnae comprising dense, very elongate pinnules; pinna in northeast quadrant comprising pinnatifid pinnules; devolatilized adpression, BB-96-30-175, x1

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PLATE 14

Figs. 1 to 4. – *Lobatopteris* sp. A

1. Fertile ultimate pinna; devolatilized adpression, BB-94-30-17, x2
2. Enlargement of Fig. 1; *Asterotheca*-type fructifications on base of pinnules (arrow); x6
3. Fertile ultimate pinna; devolatilized adpression, BB-94-30-31, x2
4. Proximal penultimate pinna fragment with thick rachis (r); devolatilized adpression, BB-96-30-175, x0.7

Figs. 5 to 10. – miospores isolated from *Asterotheca*-type fructification (BB-94-30-17; Figs. 1, 2)

5. *Laevigatosporites*-type, monolete(?), laevigate spores with thin exines; x790
6. *Torispora*- or *Crassosporites*-type, monolete(?), laevigate spore with part of exine distinctly thickened; x630
7. *Torispora*- or *Crassosporites*-type spore; x600
8. *Laevigatosporites*-type spore; x1140
9. *Laevigatosporites*-type spore; x1095
10. *Torispora*- or *Crassosporites*-type spore; x1130


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PLATE 15

Figs. 1 to 4. – *Pecopteris plumosa* (Artis) Brongniart, 1832

1. Enlargement of Fig. 4; increasingly proximal pinnae demonstrating morphological gradation from distal penultimate pinna (ipp) consisting of distal ultimate pinnae with decurrent racheis and small, semicircular pinnules→proximal ultimate pinnae (mup) consisting of large, subfalcate, decurrent, pinnatifid pinnules→proximal ultimate pinna (mue) comprising entire pinnules; x2
2. Apex of penultimate pinna; "naturally macerated" volatilized adpression, BB-97-30-236, x2
3. Acutely rounded, elongate-triangular apex of penultimate pinna; "naturally macerated" volatilized adpression, BB-97-30-237, x1
4. Antepenultimate pinna; partially "naturally macerated" volatilized adpression, BB-96-30-174, x0.7


mue
mup
ipp
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PLATE 16

Figs. 1, 2, 4, 5, 7. – *Pecopteris plumosa* (Artis) Brongniart, 1832

1. Proximal ultimate pinnae with large subfalcate pinnules; partially "naturally macerated" volatilized adpressions, BB-96-30-150, x1
2. Proximal penultimate pinna; decarbonized adpression, BB-97-30-234, x1
4. Enlargement of Pl. 15, Fig. 4; distal penultimate pinna with small, semicircular pinnules on distal ultimate pinnae; "naturally macerated" volatilized adpression, BB-96-30-174, x2
5. Proximal penultimate pinna; pinnule midveins slightly flexuous, lateral veins dichotomize once or unbranched near pinnule summit; "naturally macerated" volatilized adpression, BB-97-30-239, x2
7. Proximal penultimate pinna; partially "naturally macerated" devolatilized adpression, BB-97-30-238, x1

Figs. 3, 6. – Fern frond racheis

3. Punctate rachis; decarbonized adpression, BB-96-30-123a, x2
6. Devolatilized adpression, BB-94-30-35, x2

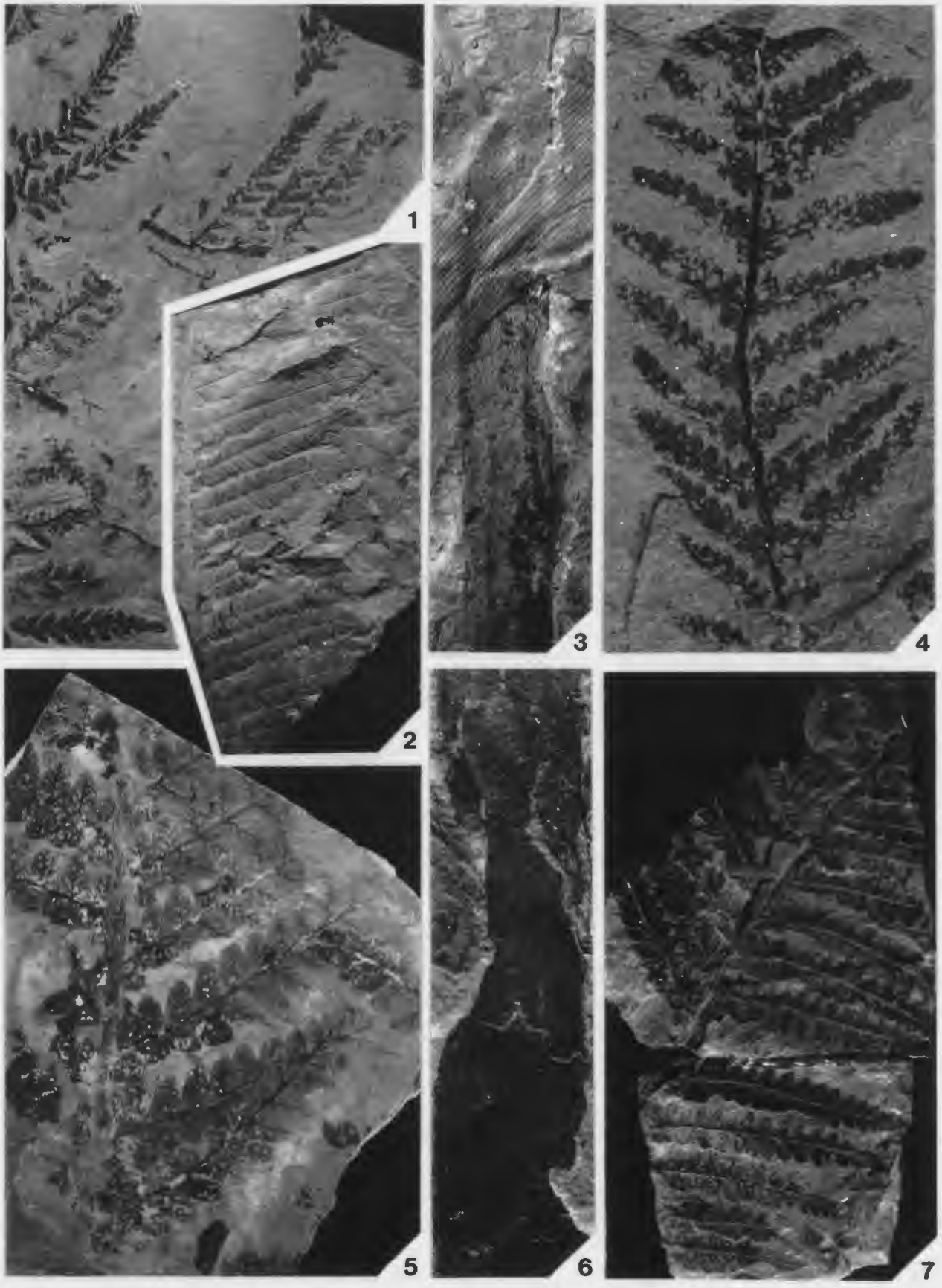
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PLATE 17

Figs. 1 to 3. – *Pecopteris* sp. cf. *P. cyathea* (Schlotheim)

1. Fertile ultimate pinna; (see venation on Fig. 4.5.6); partially "naturally macerated" volatilized adpression, BB-96-30-129, x1.5
2. Same as Fig. 1; oblique illumination to enhance fructifications; x1.5
3. Apex of ultimate pinna; pinnules with prominent, simple venation; "naturally macerated" volatilized adpression, BB-96-30-106, x1.5

Figs. 4 to 6, 9. – *Pecopteris* sp. cf. *P. herdii* Bell, 1938

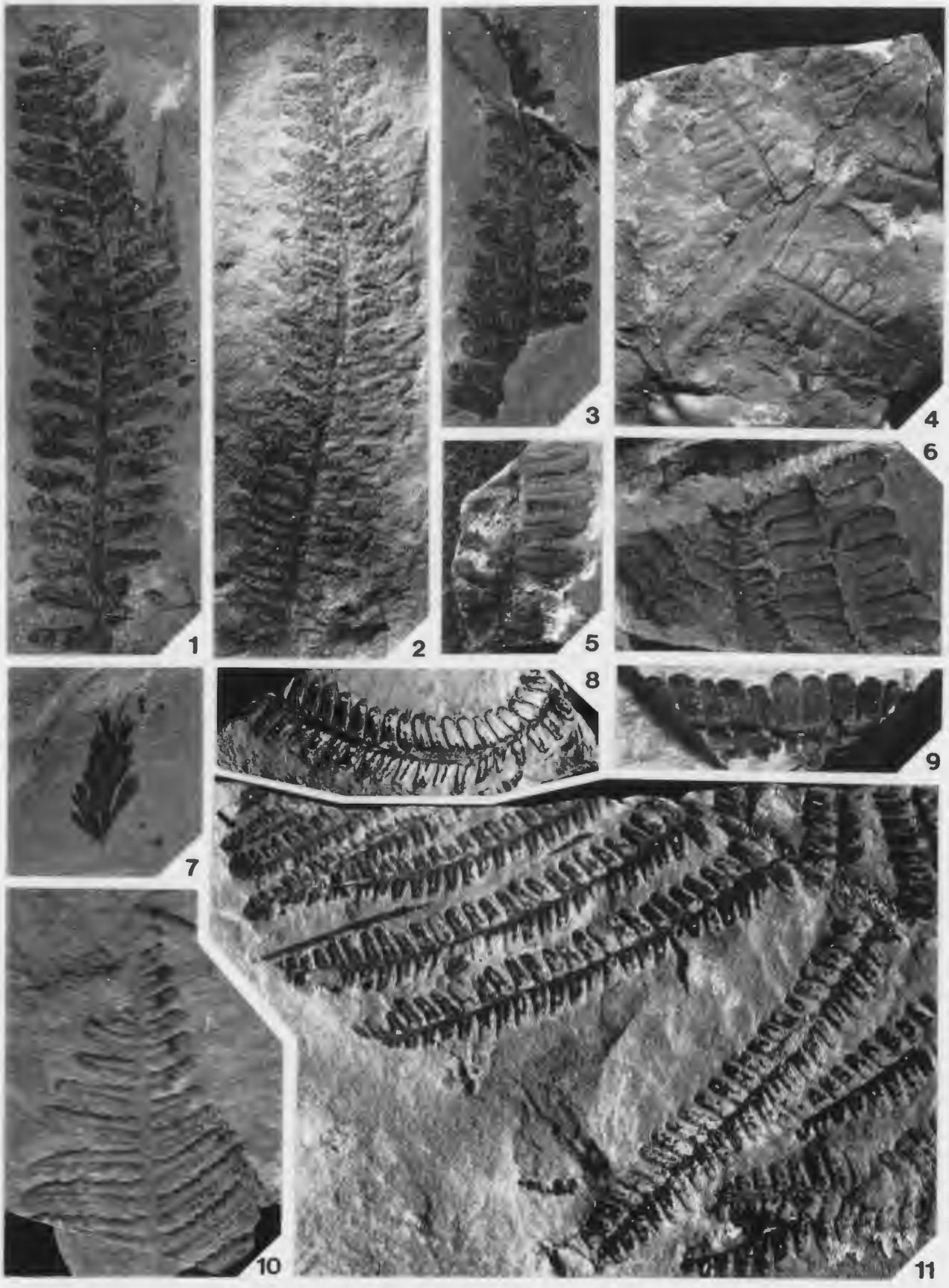
4. Penultimate pinna with thick, sparsely punctate rachis; decarbonized adpression, BB-97-30-246, x2
5. Ultimate pinna; delicate lateral veins on uppermost pinnules (see Fig. 4.5.4); decarbonized adpression, BB-97-30-247, x2
6. Ultimate pinnae; base of pinnules confluent (arrow); note fine hairs arising from pinnule surface; decarbonized adpression, BB-97-30-214, x2
9. Ultimate pinna; falsely crenulate lateral pinnule margin (arrow); devolatilized adpression, BB-94-30-8, x2

Fig. 7. – cf. *Sphenopteris* sp.

7. Apical frond element; robust terminus (t; now partially decarbonized) representing strobilus(?); "naturally macerated" volatilized adpression, BB-96-25-10, x2

Fig. 8, 10, 11. – *Pecopteris* sp. A

8. Ultimate pinna; pinnules markedly vaulted; partially decarbonized adpression, BB-94-30-27, x1.5
10. Apex of penultimate pinna; entire pinnules nearest top morphological identical to entire pinnules of proximal ultimate pinnae (cf. Figs. 8, 11; Pl. 18, Fig. 2), suggesting affinity of frond elements; decarbonized adpression, BB-94-30-20, x2
11. Penultimate pinna with morphological gradation between proximal and distal ultimate pinnae; tiny, distal pinnules (on uppermost ultimate pinnae, arrow) morphologically identical to those on distal ultimate pinnae near base of penultimate pinnae (Fig. 10; Pl. 18, Fig. 2), suggesting affinity of disparate frond elements; rachis distinctly punctate; partially decarbonized adpression, BB-94-30-36, x2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Laveineopteris rarinervis (cont.)

13. Isolated pinnule; undulate lateral margin (arrow); decarbonized adpression, BB-96-14-21

PLATE 18

Figs. 1, 2. – *Pecopteris* sp. A

1. Apex of penultimate pinna; decarbonized adpression, BB-96-25-10, x2
2. Proximal ultimate pinnae; decarbonized adpressions, BB-94-30-48, x1.5

Figs. 3, 7, 8. – *Cyclopteris* spp(?)

3. Compare fine, broadly arching venation with more flexuous venation of cyclopteroid-type pinnules attributed to *Neuropteris semireticulata* (cf. Fig. 4.8.6 and 4.8.8; Fig. 6; Pl. 23, Figs. 6, 8); "naturally macerated" devolatilized adpression, BB-96-30-133, x1.5
7. Devolatilized adpression, BB-96-30-79, x1.5
8. Devolatilized adpression, BB-96-32-2, x1.5

Fig. 4. – cf. *Alethopteris* sp. Sternberg, 1825

4. Pinnule fragment; devolatilized adpression, BB-94-30-10, x2.5

Fig. 5. – *Sphenopteris* sp. A

5. Penultimate pinna pinnules stalked near base of ultimate pinnae; devolatilized adpression, BB-96-30-90, x2

Fig. 6. – *Neuropteris semireticulata* Josten, 1962

6. Cyclopteroid-type pinnule with gently flexuous venation, hinting at affinity with *N. semireticulata* (cf. Figs. 3, 7, 8); "naturally macerated" volatilized adpression, BB-94-30-49, x1.5

Figs. 9 to 13. – *Laveineopteris rarinervis* (Bunbury) Cleal, Shute and Zodrow, 1990

9. Ultimate pinna; decarbonized adpression, BB-96-14-44, x2
10. Isolated pinnule; slightly undulate lateral margin (arrow); decarbonized adpression, BB-96-14-18, x2
11. Terminal pinnule on summit of ultimate pinna; decarbonized adpression, BB-96-14-16, x2
12. Ultimate pinnae fragments; devolatilized adpression, BB-96-14-33, x2

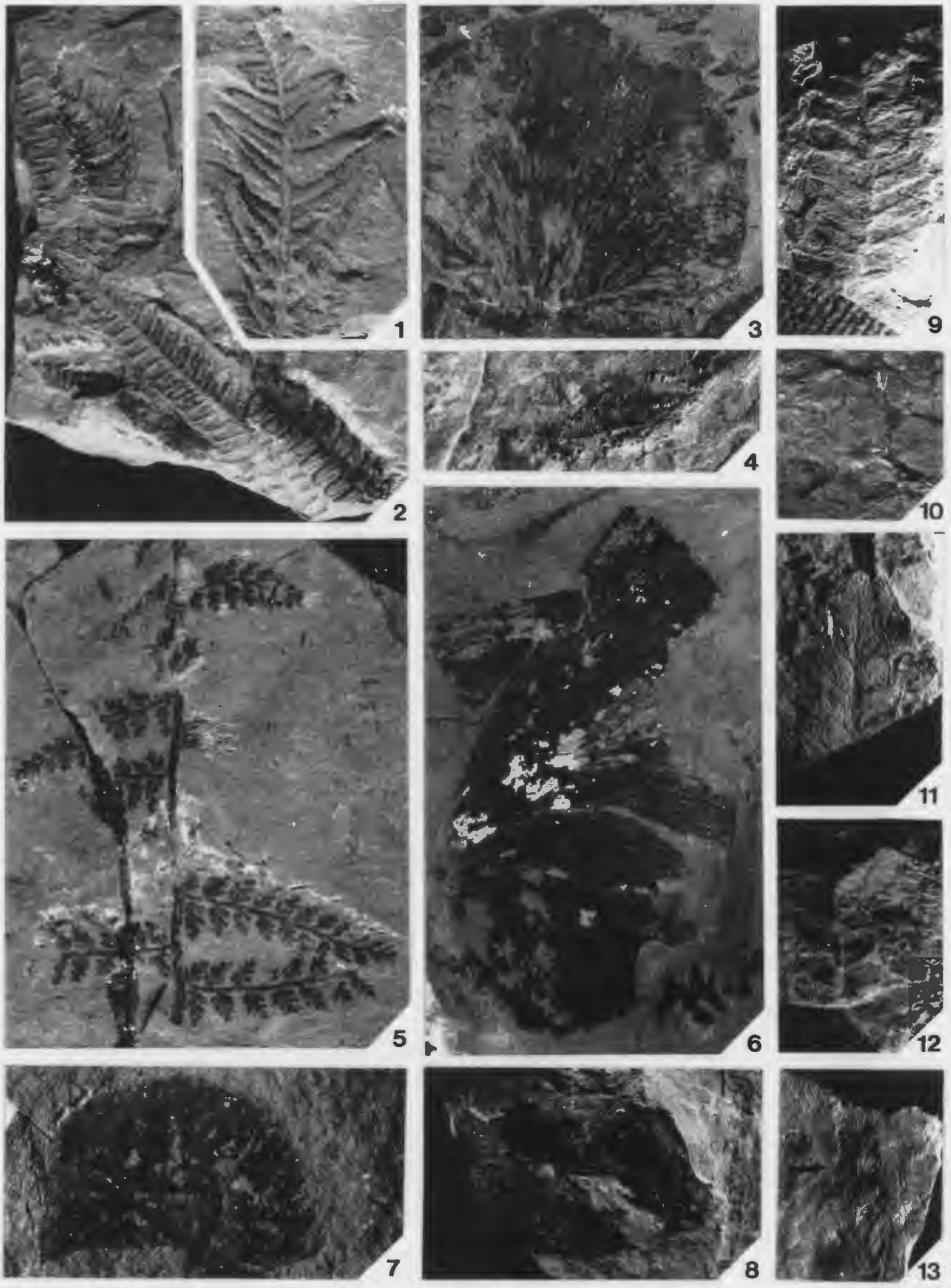

PLATE 19

Figs. 1 to 4, 9. – *Laveineopteris rarinervis* (Bunbury) Cleal, Shute and Zodrow, 1990

1. Enlargement of Pl. 18, Fig. 11; uppermost pinnules sessile, with basiscopic side occupied by thin subvein which arises directly from rachis (arrow); venation slightly flexuous, fasciculate, widely spaced; decarbonized adpression, BB-96-14-16, x12
2. Penultimate pinna; partially decarbonized adpression, BB-96-14-32, x2
3. Isolated pinnule (r); decarbonized adpression, BB-96-14-18, x2
4. Cuticles (abaxial and adaxial adjoined); macerated with Schulze's Reagent; x15
9. Fasciculate lateral veins curve apically and merge with "striate compression margin" (arrows) upon reaching lateral margin; partially decarbonized adpression, BB-96-14-35, x15

Figs. 3, 5 to 8. – cf. *Laveineopteris tenuifolia* (Sternberg) Cleal, Shute and Zodrow, 1990

3. Isolated pinnule (t); decarbonized adpression, BB-96-14-18, x2
5. Isolated pinnule fragment; gently arching lateral veins dense but distant; "naturally macerated" volatilized adpression, BB-96-14-46a, x10
6. Isolated pinnule; well developed basiscopic auricle (b); shallow indent ca. 1/3 up pinnule (arrow) diagnostic of taxa; devolatilized adpression, BB-96-30-133, x1.5
7. Isolated pinnule fragment; "naturally macerated" volatilized adpression, BB-96-14-31, x2
8. Isolated pinnule fragment; "naturally macerated" volatilized adpression, BB-96-14-24b, x2


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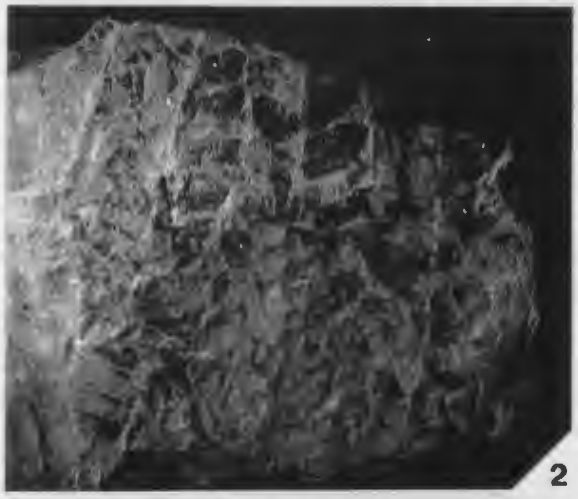
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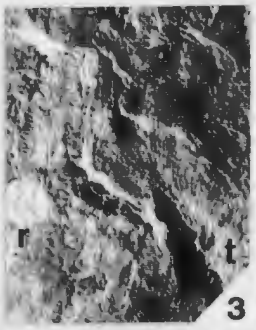
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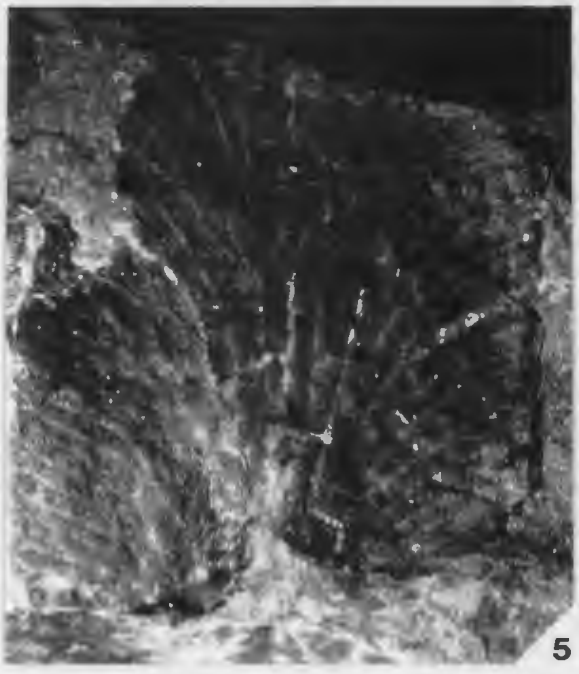
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PLATE 20

Figs. 1, 2, 4, 5. – cf. *Laveineopteris tenuifolia* (Sternberg) Cleal, Shute and Zodrow, 1990

1. Ultimate pinna; diagnostic shallow indent ca. 1/4 to 1/3 up lateral margin; well developed basiscopic auricles in lowermost pinnules; partially decarbonized adpression, BB-96-30-67/68, x1.5
2. Isolated pinnule; gently arching lateral veins; shallow indent of lateral margin; prominent compression margin (arrow); "naturally macerated" volatilized adpression, BB-96-14-9, x9
4. Cuticles (abaxial and adaxial adjoined); compression margin (arrow); macerated with Schulze's Reagent; x12
5. Enlargement of Pl. 19, Fig. 8; "naturally macerated" volatilized adpression, BB-96-14-24, x6

Figs. 3, 6 to 11. – *Linopteris neuropteroides* (Gutbier) Zeiller, 1899

3. Isolated subfalcate pinnule; decarbonized adpression, BB-96-19-16, x2
6. Isolated pinnule; thicker, more flexuous veins than typical of the taxa, possibly because fine details better preserved in mudstone; decarbonized adpression, BB-96-19-25, x2
7. Isolated subfalcate pinnule fragment; partially decarbonized adpression, BB-96-19-33, x2
8. Isolated pinnule; well preserved venation; decarbonized adpression, BB-96-19-40, x2
9. Isolated rotund pinnule; decarbonized adpression, BB-96-19-22, x2
10. Isolated subfalcate pinnule; decarbonized adpression, BB-96-19-4, x2
11. Isolated subfalcate pinnule; partially decarbonized adpression, BB-96-19-27, x2

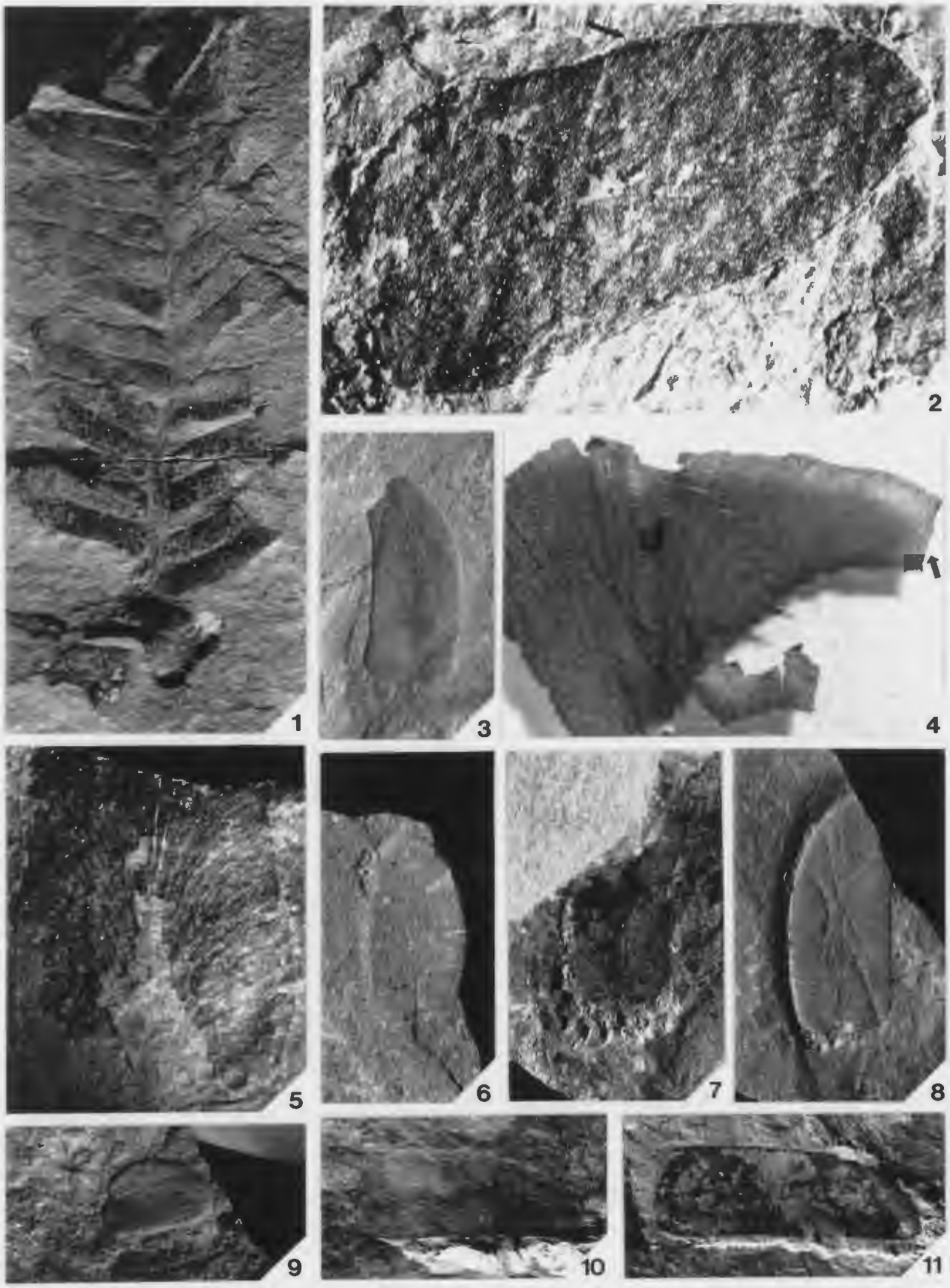

PLATE 21

Figs. 1, 5. – *Linopteris neuropteroides* (Gutbier) Zeiller, 1899

1. Enlargement of Pl. 20, Fig. 8; anastomosing venation; tiny pits on pinnule surface may represent punctae(?); decarbonized adpression, BB-96-19-40, x5
5. Enlargement of Pl. 20, Fig. 6; slightly flexuous, anastomosing venation; tiny, hairs (arrows) on pinnule surface; decarbonized adpression, BB-96-19-25, x7

Fig. 2. – Pteridosperm frond rachis

2. Faint, longitudinal striae superimposed on wrinkled surface; decarbonized adpression, BB-96-14-7, x1

Figs. 3, 4. – *Macroneuropteris scheuchzeri* (Hoffman) Cleal, Shute and Zodrow, 1990

3. Enlargement of Fig. 4; longitudinally oriented hairs on pinnule surface; x8.7
4. Isolated, elongate, villous pinnule with dense venation; devolatilized adpression, BB-96-14-35, x3.4

Figs. 6, 7. – *Neuropteris semireticulata* Josten, 1962

6. Ultimate pinna; pinnules increasingly sessile apically; latex peel, BB-96-30-123a, x1.5
7. Ultimate pinna; flexuous to pseudoanastomosing venation; latex peel, BB-96-30-69, x1.5

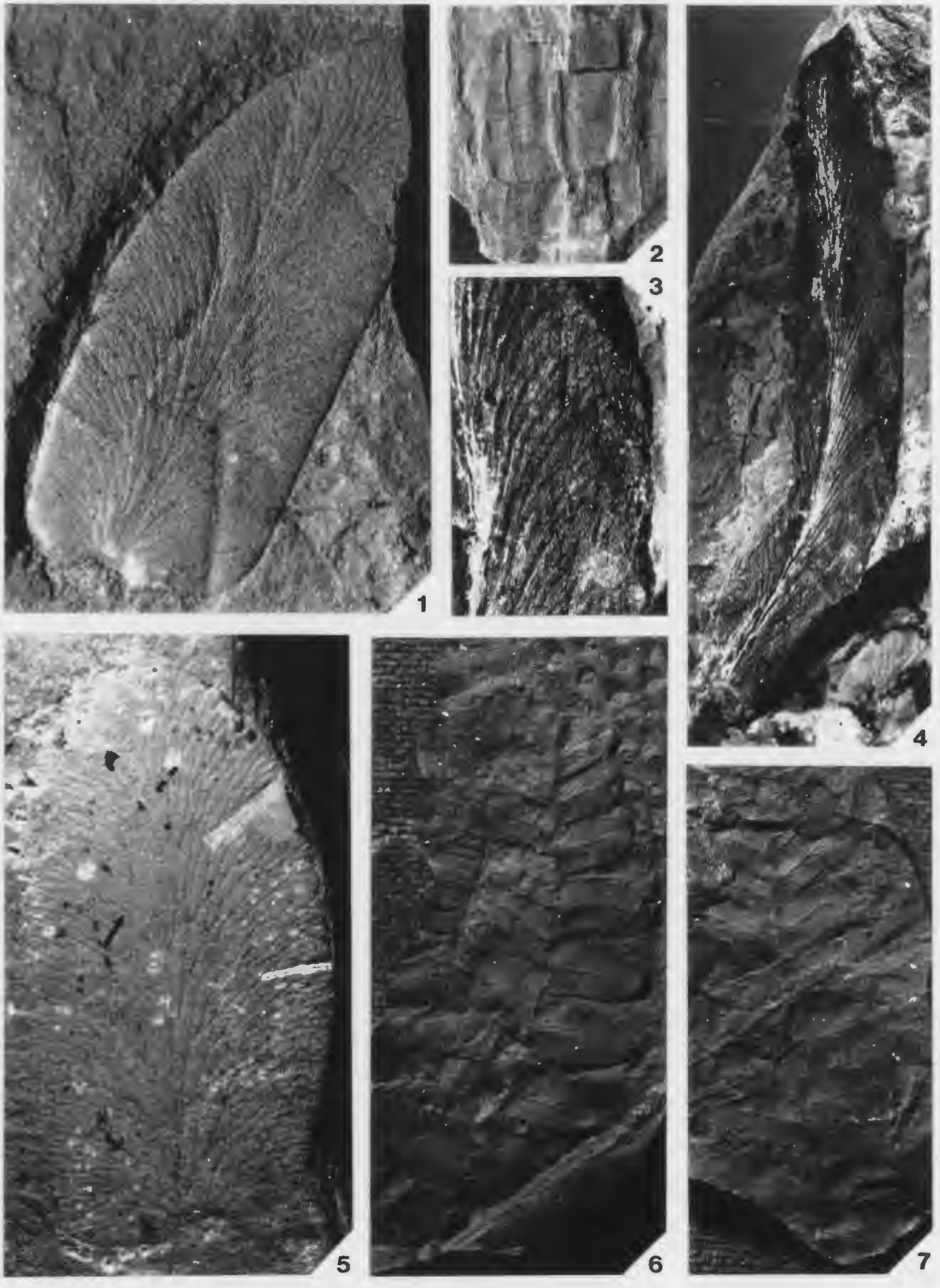
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PLATE 22

Figs. 1 to 13. – *Neuropteris semireticulata* Josten, 1962

1. Ultimate pinna; rachis overlapped by acroscopic auricles of pinnules; well preserved pseudoanastomising venation; "naturally macerated" volatilized adpression, BB-96-25-38, x2
2. Rhombic terminal pinnule; decarbonized adpression, BB-96-25-23, x2
3. Rhombic terminal pinnule fragment; devolatilized adpression, BB-96-25-24, x2
4. Apex of ultimate pinna; latex peel, BB-96-30-96, x2
5. Apex of ultimate pinna; rachis overlapped by acroscopic auricles, but pinnules increasingly sessile apically; terminal pinnule deltoid or elongate-triangular; decarbonized adpression, BB-96-30-125, x1.5
6. Large forma *impar*-type pinnule fragment with flexuous venation (see Fig. 4.8.5); decarbonized adpression, BB-97-30-181, x2
7. Ultimate pinna fragment; latex peel, BB-94-30-6, x1.5
8. Apex of large, subtriangular forma *impar*-type pinnule; venation on acroscopic side less flexuous, more dense and more broadly arching than that of basiscopic side (cf. Fig. 12); latex peel, BB-96-30-133, x2
9. Apex of ultimate pinna; "naturally macerated" devolatilized adpression, BB-97-30-262, x1.5
10. Ultimate pinna; rachis overlapped by acroscopic auricles (arrow); latex peel, BB-94-30-49, x1.5
11. Hastate, forma *impar*-type pinnule with prominent auricle and flexuous venation; devolatilized adpression, BB-96-30-115, x2
12. Same as Fig. 8; venation on basiscopic side more flexuous and widely spaced; x2
13. Apex of ultimate pinna; subtriangular pinnules with flexuous venation; devolatilized adpression, BB-30-96-101, x1.5

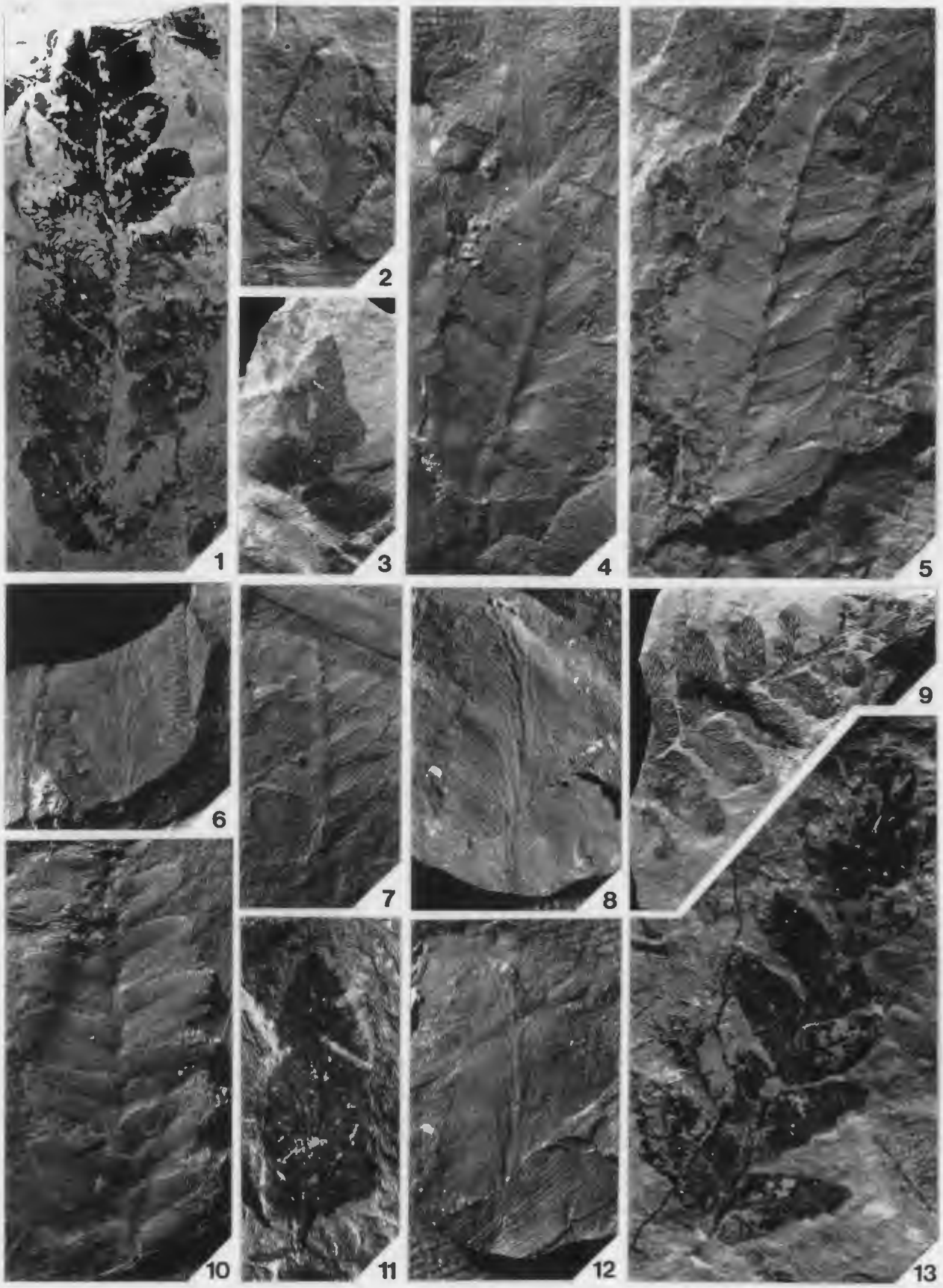
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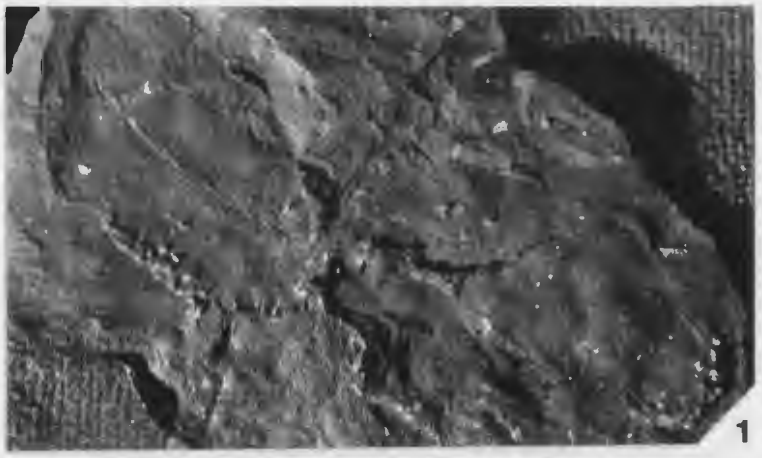
PLATE 23

Figs. 1 to 10. – *Neuropteris semireticulata* Josten, 1962

1. Asymmetrical, curved, forma *impar*-type pinnules arising from striate rachis; latex peel, BB-96-30-72, x1.5
2. Forma *impar*-type pinnule; venation on acroscopic side less flexuous, more dense and more broadly arching than that of basiscopic side (cf. Fig. 3); partially decarbonized adpression, BB-96-30-89, x2
3. Same as Fig. 2; venation on basiscopic side more flexuous and widely spaced, x2
4. Flexuous venation of forma impar-type (fi) and "normal" lateral pinnules; "naturally macerated" volatilized adpressions, BB-96-25-32, x2
5. Elongate-linguaeform "normal" lateral pinnules; devolatilized adpression, BB-94-30-53, x2
6. Cyclopteroid-type pinnule with gently flexuous venation; decarbonized adpression, BB-96-30-72, x1.5
7. Forma *impar*-type pinnules arising from striate rachis; venation on acroscopic side (ac) less flexuous, more dense and more broadly arching than that of basiscopic side; latex peel, BB-96-30-144, x2
8. Fragment of cyclopteroid-type pinnule with gently flexuous venation (see Fig. 4.8.6); "naturally macerated" devolatilized adpression, BB-96-25-29, x2
9. Cuticles (adaxial and abaxial adjoined) of terminal pinnule; macerated with Schulze's Reagent; x8
10. Linguaeform, "normal" pinnules; devolatilized adpression, BB-96-30-66, x2



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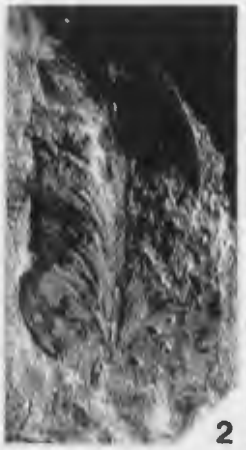

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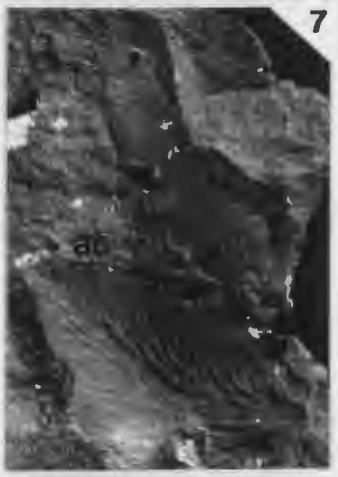

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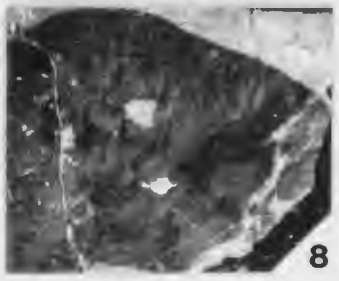

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PLATE 24

Figs. 1 to 4, 7. – *Cordaites* sp. cf. *C. borassifolia* (Sternberg) Unger, 1850

1. Single, prominent intermediate sclerotic strand between primary veins (arrow); decarbonized adpression, BB-94-30-6, x1
2. Devolatilized adpression, BB-96-30-71, x1.5
3. Devolatilized adpression, BB-96-30-72, x1
4. Enlargment of Fig. 3; single, intermediate sclerotic strand between primary veins, x8
7. Well preserved intermediate sclerotic strands; strand arising from area of primary vein(?) (arrow); "naturally macerated" volatilized adpression, BB-94-30-23, x8

Figs. 5, 6, 8, 9. – *Cordaites* sp. cf. *C. principalis* (Germer) Geinitz, 1855

5. Frequency of primary veins increasing at lateral leaf margin (arrow); partially decarbonized adpression, BB-96-30-123a, x1
6. Leaf widening distally from swollen leaf base (b); decarbonized adpression, BB-96-30-151, x2
8. Space between primary veins flattened (cf. Fig. 9), and occupied by prominent central intermediate sclerotic strand and less conspicuous lateral sclerotic strands; partially decarbonized adpression, BB-96-30-151, x8
9. Space between primary veins vaulted (cf. Fig. 8); more prominent intermediate sclerotic strand (arrow); decarbonized adpression, BB-94-30-18, x8

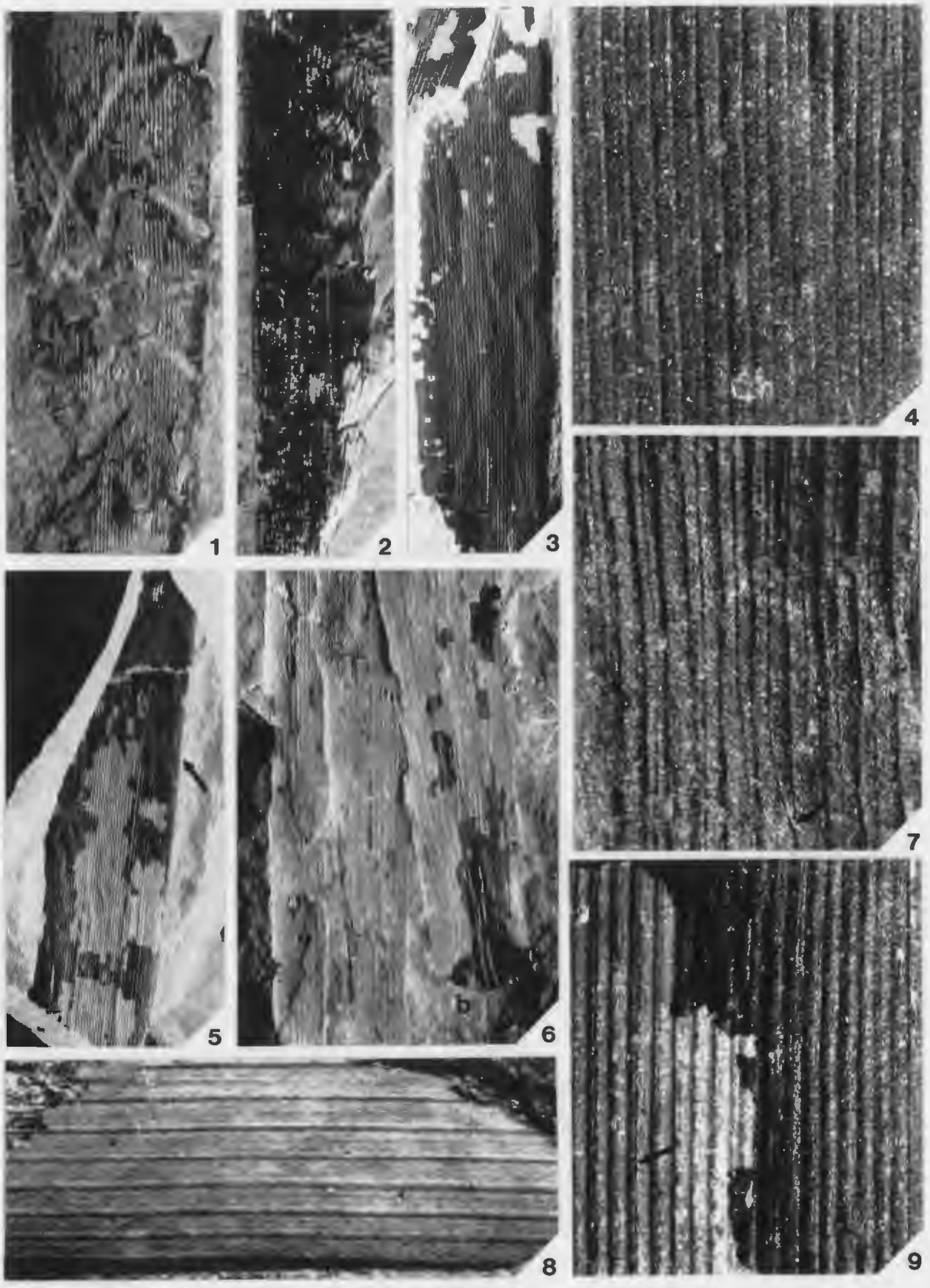
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PLATE 25

Figs. 1 to 3, 6. – *Cordaites* sp. cf. *C. principalis* (Germer) Geinitz, 1855

1. Frequency of primary veins increasing at lateral margin (arrow); partially decarbonized adpressions, BB-94-30-5, x1
2. Very low angle bifurcation of primary veins; devolatilized adpression, BB-94-30-35, x1
3. Spaces between primary veins flattened and occupied by well preserved central and intermediate sclerotic strands; "naturally macerated" volatilized adpression, BB-96-30-151, x8
6. Cuticles (abaxial and adaxial superimposed); prominent central intermediate sclerotic strand and less conspicuous lateral sclerotic strands; x6

Figs. 4, 5, 8. – *Cordaites* sp. A

4. Enlargement of Fig. 5; spaces between primary veins absent of sclerotic strands; x8
5. Devolatilized adpression, BB-96-30-113, x2
8. Very low angle bifurcation of primary veins; devolatilized adpression, BB-94-30-11, x1.5

Fig. 7. – *Cordaites* sp. B

7. Enlargement of Pl. 26, Fig. 3; comparatively smooth but longitudinally "striate" leaf surface; more prominent ribs (arrow) may represent primary veins; devolatilized adpression, BB-96-34c-1, x8


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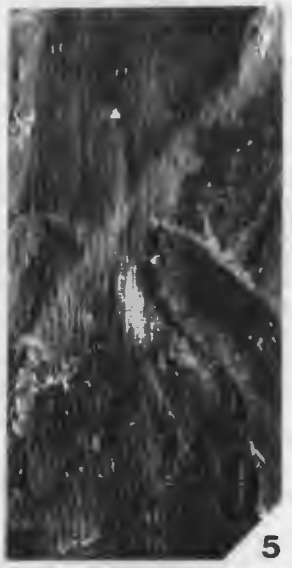
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8

Fig. 11. – *Dadoxylon* sp. Endlicher, 1847

11. Thin section in transverse plane (i.e. perpendicular to growth axis); vascular rays (vr) comprise vascular ray cells; tracheid (t) cell walls slightly contorted by compression; biserial, dome-shaped bordered pits (arrows) project into cell cavity; volatilized petrifaction, BB-97-23-2, x200

PLATE 26

Fig. 1. – *Cordaitanthus* sp. B

1. Devolatilized adpression, BB-97-30-209, x2

Figs. 2, 3. – *Cordaites* sp. B

2. Wide leaf, split longitudinally; devolatilized adpression, BB-96-34c-3, x1
3. Leaf split by mechanical abrasion(?); devolatilized adpression, BB-96-34c-1, x1

Fig. 4. – *Cordaitanthus* sp. A

4. Uncompressed, "ovate" secondary axes (sa) arise from axils of elongate sterile bracts (b); filamentous processes (fp) arising from secondary axes; devolatilized adpression. BB-96-30-108, x6

Figs. 5, 6, 9. – *Samaropsis* spp.

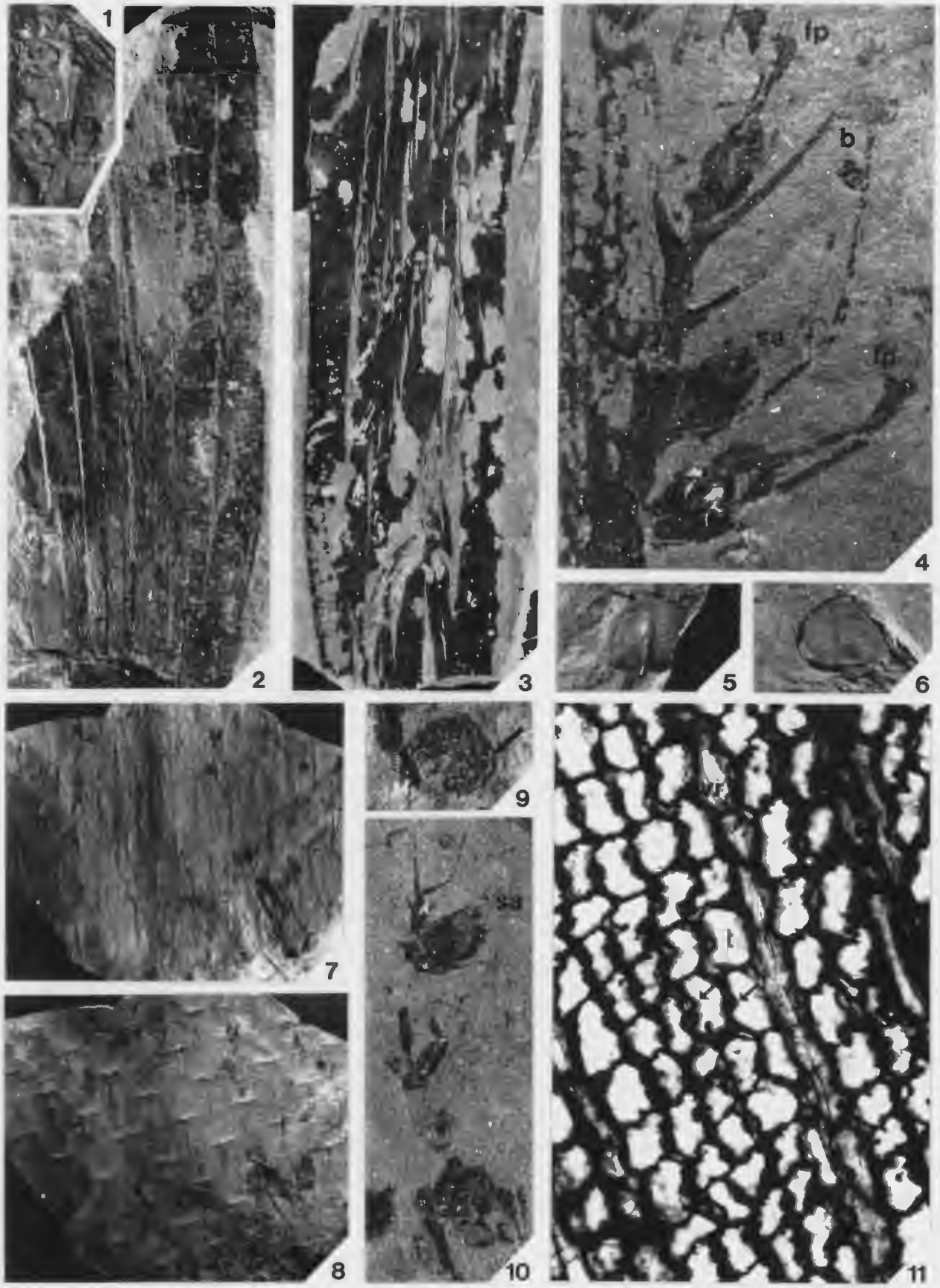
5. Micropyle (arrow); decarbonized adpression, BB-96-30-184, x2
6. Smooth surface; imprint of sarcotesta enveloping seed; decarbonized adpression, BB-96-30-108, x2
9. Reticulate surface; imprint of sarcotesta (arrow); devolatilized adpression, BB-96-30-119, x2

Figs. 7, 8. – Axis of cordaitean(?) affinity

7. Longitudinally wrinkled or striate axis; decarbonized adpression, BB-96-25-40, x1
8. Same as Fig. 7; different illumination to show helically disposed rows on lenticular swellings; x1

Fig. 10. – cf. *Cordaitanthus* sp. Feistmantel, 1876

7. Large, fertile secondary axis (sa) nestled between short sterile bracts; devolatilized adpression, BB-96-30-116, x2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Chapter 5 – Biostratigraphic Correlation and Age Determination

Western Newfoundland evidently was part of the Europe Paleoarea (Cleal and Thomas 1991) of the Euramerian Paleokingdom (Chaloner and Meyen 1973) during the Late Carboniferous (Fig. 1.2). Accordingly, it is reasonable to attempt biostratigraphic correlation of the macrofloral assemblage recovered from Blanche Brook with better established assemblages from other parts of the Europe Paleoarea. In particular, homotaxial comparisons with adpressed macroflora from localities in the Maritimes Basin and western and central Europe will either confirm or contradict the previously proposed Bolsovian (Hyde et al. 1991) or Westphalian D ages (Hacquebard et al. 1961) based on evidence from miospore assemblages.

Comparisons with macroflora in midcontinental North America may be less reliable, as it has long been recognized (e.g., Dawson 1891; Bell 1929, 1944) that the northern Appalachian mountains formed a partial barrier to faunal and (in part) floral migration between the "Acadian Province" (*sensu* Pfefferkorn and Gillespie 1980, includes Maritimes Basin) and the "Interior-Appalachian Province" of midcontinental North America. However, despite these restrictions to migration and consequent endemism, there are several cosmopolitan taxa occurring in both phytochoria that permit some comparison between the BBA and macroflora of midcontinental North America.

Based on the limited thickness of the stratigraphic section at Blanche Brook (ca. 165 m), it is postulated that all of the macrofloral subassemblages that constitute the BBA accumulated in a very short span of geological time, probably on the order of thousands to hundreds of thousands of years. As such, the entire BBA represents a temporally

restricted fossil assemblage, within which there is no record of first or last appearances of taxa. This makes biostratigraphic correlation somewhat uncertain, although Cleal (1991, p.183-184) reassures that at least tentative correlations can be made if the assemblage has a reasonable taxonomic diversity.

5.1 Established Macrofloral Biostratigraphic Classifications

5.5.1 Maritimes Basin

Extensive investigations of macroflora from the Morien Group of Sydney Coalfield led Bell (1938) to establish three consecutive macrofloral zones (*Lonchopteris eschweileriana*, *Linopteris obliqua* and *Ptychocarpus unitus* biozones; Fig. 5.1) that facilitated correlations with localities in western Europe, eastern U.S.A., and eastern Canada [e.g., Stellarton Basin (Bell 1940), Cumberland Basin (Bell 1944), New Brunswick Platform (Bell 1962); summarized in Lyons and Zodrow (1995)]. The ages of Bell's (1938) biozones were redefined by Hacquebard et al. (1961) based on palynological evidence; Zodrow and McCandlish (1978) accordingly eliminated the *P. unitus* Biozone by extension of the *L. obliqua* Biozone. Biostratigraphic ranges have since been further refined in Sydney Coalfield by E.L. Zodrow and colleagues (Gastaldo and Zodrow 1982; Zodrow 1982, 1986, 1989a, b, 1990), which has permitted comparison with contemporaneous strata of western Europe (Zodrow and Cleal 1985) and the Mabou Basin of western Cape Breton Island (Zodrow and Vasey 1986).

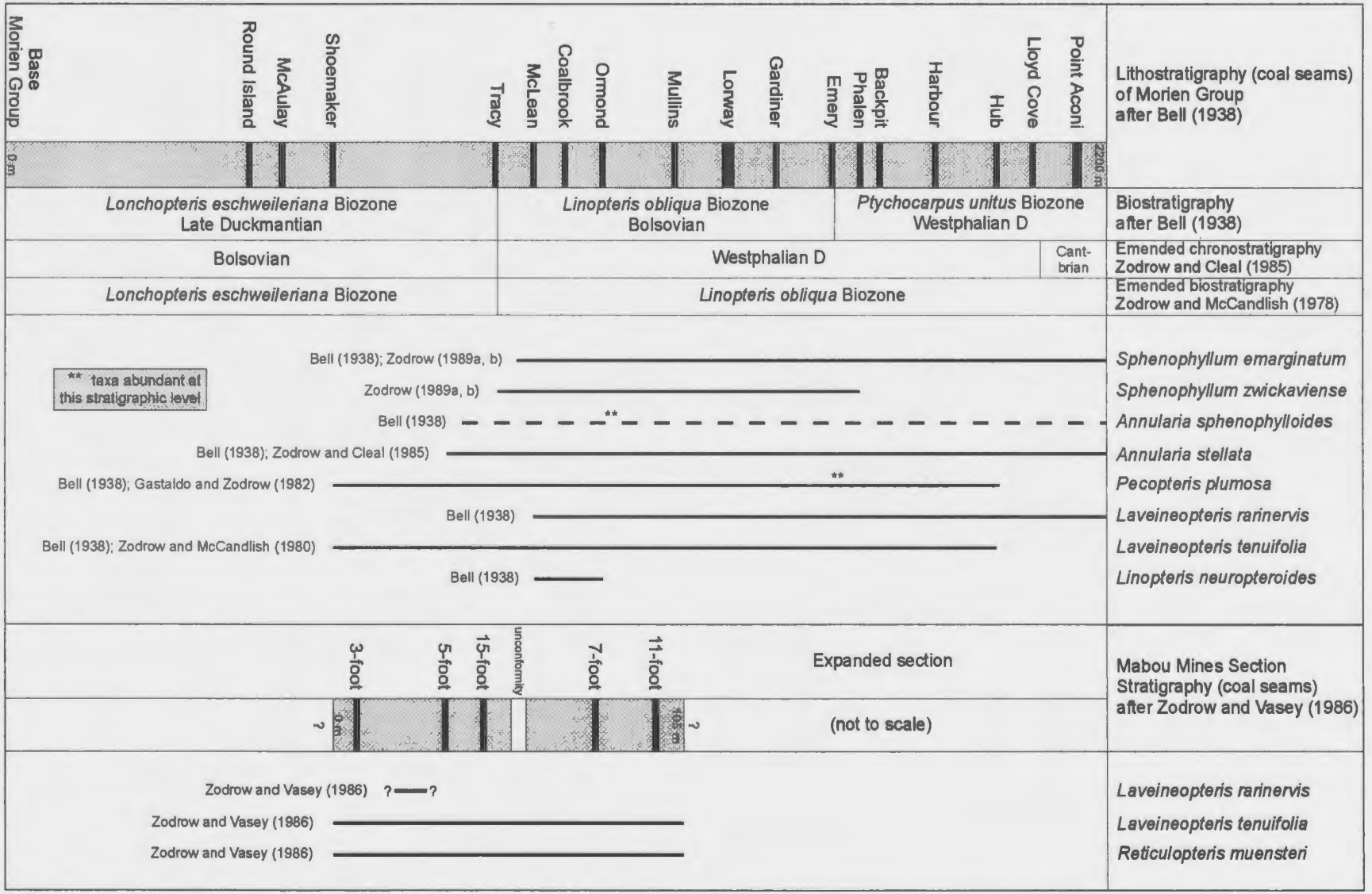


Figure 5.1. Biostratigraphic ranges of selected taxa from the Blanche Brook Assemblage as determined in the Sydney Basin (Morien Group) and Mabou Basin (Inverness Formation).

5.1.2 Western and Central Europe

By far the most comprehensive biostratigraphic classification of Carboniferous adpressed macroflora was assembled by Wagner (1984), who recognized sixteen distinct (assemblage) biozones. Although this classification was based primarily on data from western and central Europe, it was intended to facilitate biostratigraphic correlation within the entire paleoequatorial belt. Refinement of the biostratigraphic scheme (Fig. 5.2) has significantly improved its resolution, in particular the recognition and delineation of several subbiozones by Cleal (1984, 1991).

5.1.3 Midcontinental North America

The most significant biostratigraphic classification for Upper Paleozoic strata of U.S.A. was introduced by Read (*in* Moore et al. 1944) and Read and Mamay (1964), and comprises fifteen macrofloral zones. In addition, Darrah (1969, p. 65) recorded the distribution of major plant taxa within lithostratigraphic units of the Appalachian region, and attempted chronostratigraphic correlation of Midcontinental North American chronozones with those of Europe (see also Pfefferkorn and Gillespie 1980, p. 102). More recently, Gillespie et al. (1995) have produced an emended classification (Fig. 5.3) providing correlation between: (i) lithostratigraphic units of the Appalachian region; (ii) chronostratigraphic units of the North American Midcontinent and western and central Europe; and (iii) Read and Mamay's (1964) floral zones.

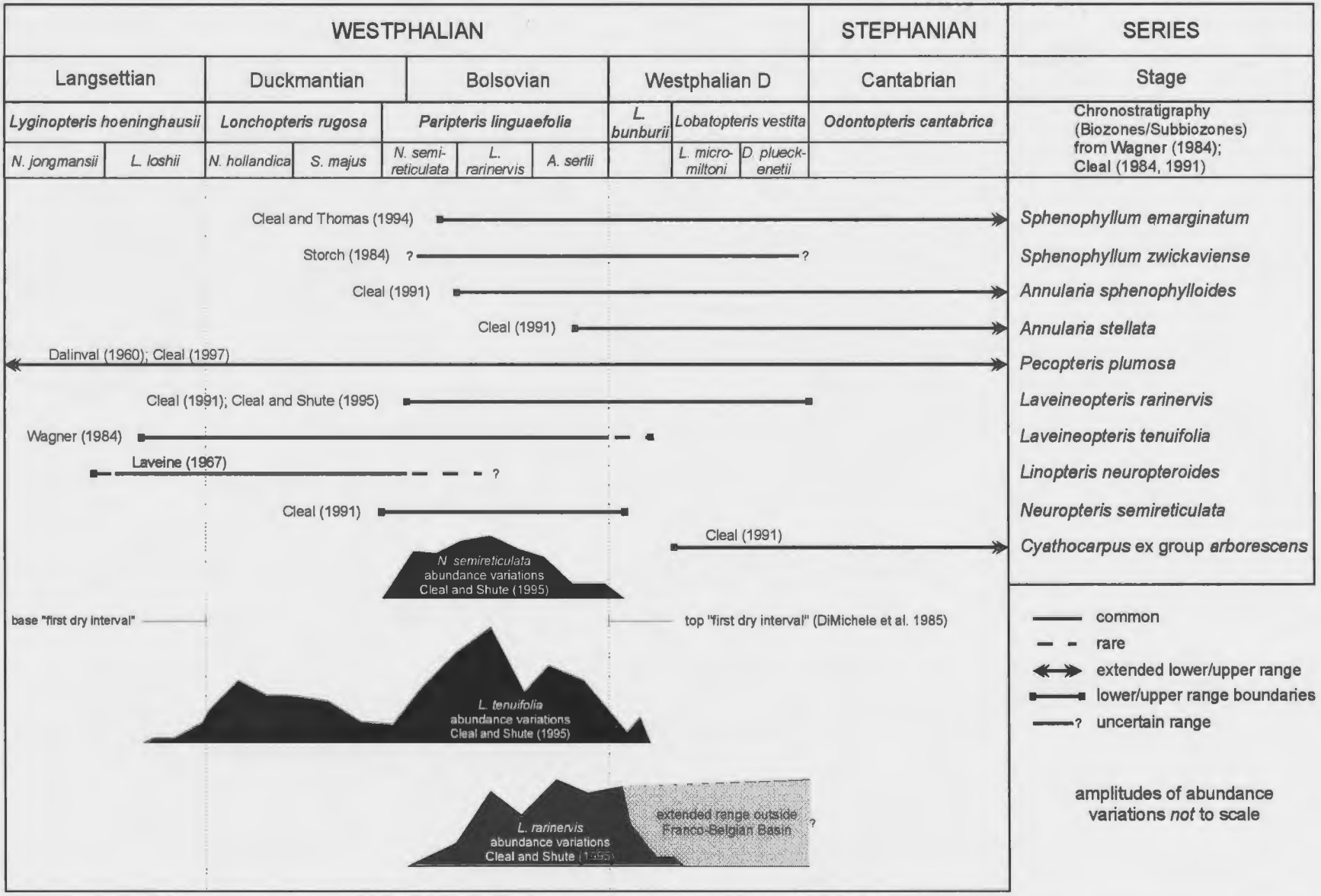


Figure 5.2. Biostratigraphic ranges of selected taxa from the Blanche Brook Assemblage as determined in western and central Europe.

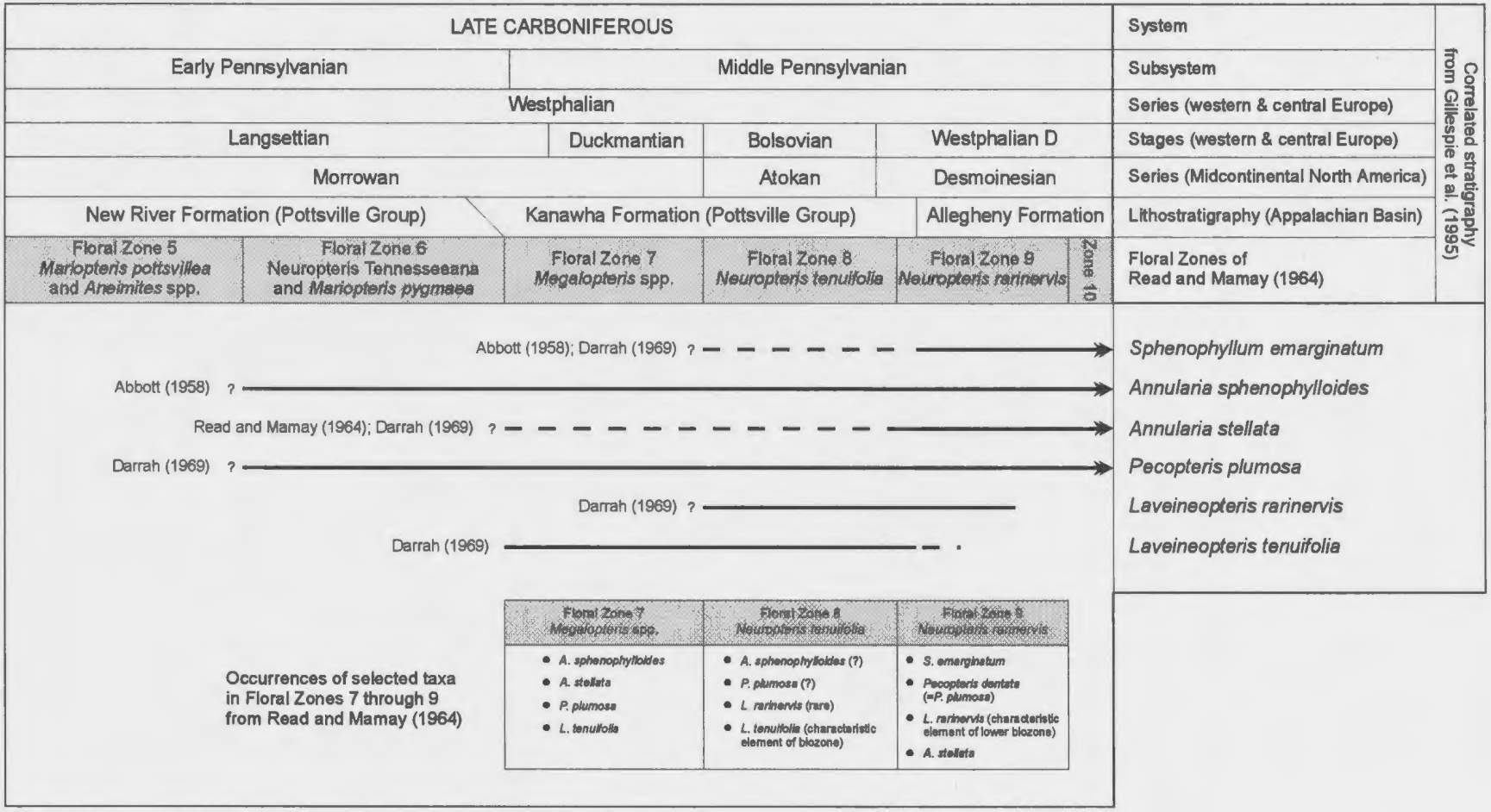


Figure 5.3. Biostratigraphic ranges of selected taxa from the Blanche Brook Assemblage as determined in midcontinental North America.

5.2 Selection of Biostratigraphically Significant Macroflora

Nine foliar form-taxa – four sphenopsids (*Sphenophyllum emarginatum*, *S.* sp. cf. *S. zwickaviense*, *Annularia sphenophylloides*, *A. stellata*), one fern (*Pecopteris plumosa*) and four pteridosperms (*Laveineopteris rarinervis*, cf. *L. tenuifolia*, *Linopteris neuropteroides*, *Neuropteris semireticulata*) – were selected from the BBA for comparison with macrofloral assemblages of the Sydney and Mabou basins of the Maritimes Basin (Fig. 5.1), western and central Europe (Fig. 5.2), and midcontinental North America (Fig. 5.3). Selection was based on these criteria: that specimens (i) are sufficiently abundant in the BBA and/or well enough preserved that they could be confidently determined to the specific level; (ii) are not endemic species, but rather have a wide biogeographic distribution throughout much of the Europe Paleoarea; and (iii) have well established biostratigraphic ranges in other parts of the Europe Paleoarea.

5.3 Age Determination from Biostratigraphic Correlation

5.3.1 Maritimes Basin

Homotaxial comparison of the selected taxa (i.e., together as a group) from Blanche Brook with macroflora of the Morien Group of the Sydney Basin and the Mabou Mines Section (MMS) of the Mabou Basin indicates that the BBA may be equivalent to an interval within a range extending from the upper *L. eschweileriana* Biozone to lower (or middle?) *L. obliqua* Biozone (Fig. 5.1). According to Zodrow and McCandlish (1978), this biostratigraphic interval is correlative with the late Bolsovian through early (or middle?) Westphalian D stages of Europe. In particular, *L. neuropteroides* may be a

very useful biostratigraphic indicator, as it is recorded in the Sydney Basin from only a short interval in the lower *L. obliqua* Biozone (= early Westphalian D).

It is worth noting that biostratigraphic studies in the Sydney Basin, especially in recent years, have primarily involved Westphalian D strata (i.e., rocks above Tracy Seam, Fig. 5.1). Accordingly, more intense investigation of older (Bolsovian) strata (especially below Shoemaker Seam) may reveal that the bottom ranges of these and other taxa are in fact lower (and thus older) than is presently assumed. If so, the BBA could in fact be slightly older than can presently be inferred from homotaxial comparison with the Sydney Basin.

N. semireticulata, which characterizes the BBA, is apparently absent at other localities within the Maritimes Basin. However, the stratigraphic range of *Reticulopteris muensteri* in the Mabou Basin has been included in Figure 5.1 because it is considered that at least some specimens of *R. muensteri* recorded by E.L. Zodrow from the MMS may actually represent *N. semireticulata* (K.-H. Josten *in* Zodrow and Vasey 1986, p. 217).

5.3.2 Western and Central Europe

Comparison of biostratigraphic ranges of selected taxa in western and central Europe (Fig. 5.2) clearly demonstrates that the BBA is equivalent to part of the *Paripteris linguaefolia* Biozone of Wagner's (1984) classification, which envelopes the entire Bolsovian. This conclusion is supported by recent work of Cleal and Shute (1995), who showed that *N. semireticulata*, *L. rarinervis* and *L. tenuifolia* are most abundant in Bolsovian strata of the Franco-Belgian Basin (based on data from Laveine 1967).

Because range limits of taxa cannot be attained within the section at Blanche Brook, it is neither practical (nor justifiable) to attempt further refinement of the age of the BBA by attempting to determine a correlative subbiozone within the *P. linguaefolia* Biozone. However, the presence of *L. rarinervis* in combination with *A. stellata* does suggest inclusion in the *A. serlii* Subbiozone, which is correlative with the late Bolsovian.

5.3.3 Midcontinental North America

Although *S. emarginatum*, *A. sphenophylloides*, *A. stellata* and *P. plumosa* are azonal species in midcontinental North America, *L. rarinervis* and *L. tenuifolia* both are biostratigraphically diagnostic taxa. The distributions of these neuropteroids (Fig. 5.3) indicate that the BBA probably correlates with an interval within a range spanning the entire Floral Zone 8 (*N. tenuifolia* Biozone) to lower part of Floral Zone 9 (*N. rarinervis* Biozone) of Read and Mamay (1964). According to stratigraphic correlations of Gillespie et al. (1995), this interval is equivalent to the entire Atokan and early Desmoinesian Series of Midcontinental North America, and to the entire Bolsovian to early Westphalian D stages of western and central Europe.

5.4 Biostratigraphic Implications of Pecopterids in Assemblage

A considerable number of authors have noted changes in diversity and dominance patterns between different pecopterid groupings at or very near the Bolsovian/Westphalian D boundary at numerous localities within the Europe Paleoarea (e.g., Bell 1938, 1944; Read and Mamay 1964; Darrah 1969; Gillespie and Pfefferkorn 1979; Gastaldo and Zodrow 1982; Wagner 1984; Zodrow 1990). In general, pecopterids

are rather uncommon elements of adpression assemblages of Bolsovian or older age (Pfefferkorn and Thomson 1982), and when present, often are members of Corsin's (1951) *Pecopteris plumosa-dentata* (e.g., *P. plumosa*) and *P. miltoni* (e.g., *Lobatopteris miltoni*, "*P. abbreviata*") Groups. At or near the Westphalian D boundary, however, pecopterids seem to have diversified rapidly, particularly taxa belonging to Corsin's *P. arborescens* Group (e.g., *Cyathocarpus cyathea*, *Cyathocarpus arborescens*; see range of *Cyathocarpus* ex group *arborescens* on Fig. 5.2).

Although pecopterids are very common elements of the BBA, they are of limited diversity and are characterized by *P. plumosa* and a taxon (*Lobatopteris* sp. A) that is interpreted as a representative of the *P. miltoni* Group of Corsin (1951). In comparison, taxa of the *P. arborescens* Group are very rare at the site, and are represented by only two ultimate pinnae tentatively identified as *P.* sp. cf. *P. cyathea* (seven small frond fragments identified as *Pecopteris* sp. A may also be members of the group). As such, biostratigraphic evidence deduced from pecopterid distribution and abundance indicates that the BBA likely is Bolsovian in age (or at least older than Westphalian D).

5.5 Paleoecological Considerations in Age Determination

Major climatic shifts during the Late Carboniferous that resulted in broad increasingly wetter or drier intervals have been recognized by recording variations in abundance of coal swamp inhabiting vegetation (Fig. 5.4; e.g., Phillips 1979, 1981; Phillips and Peppers 1984; DiMichele et al. 1985; Phillips et al. 1985). Similarly, although far more difficult, it has also been possible to detect these same broad changes

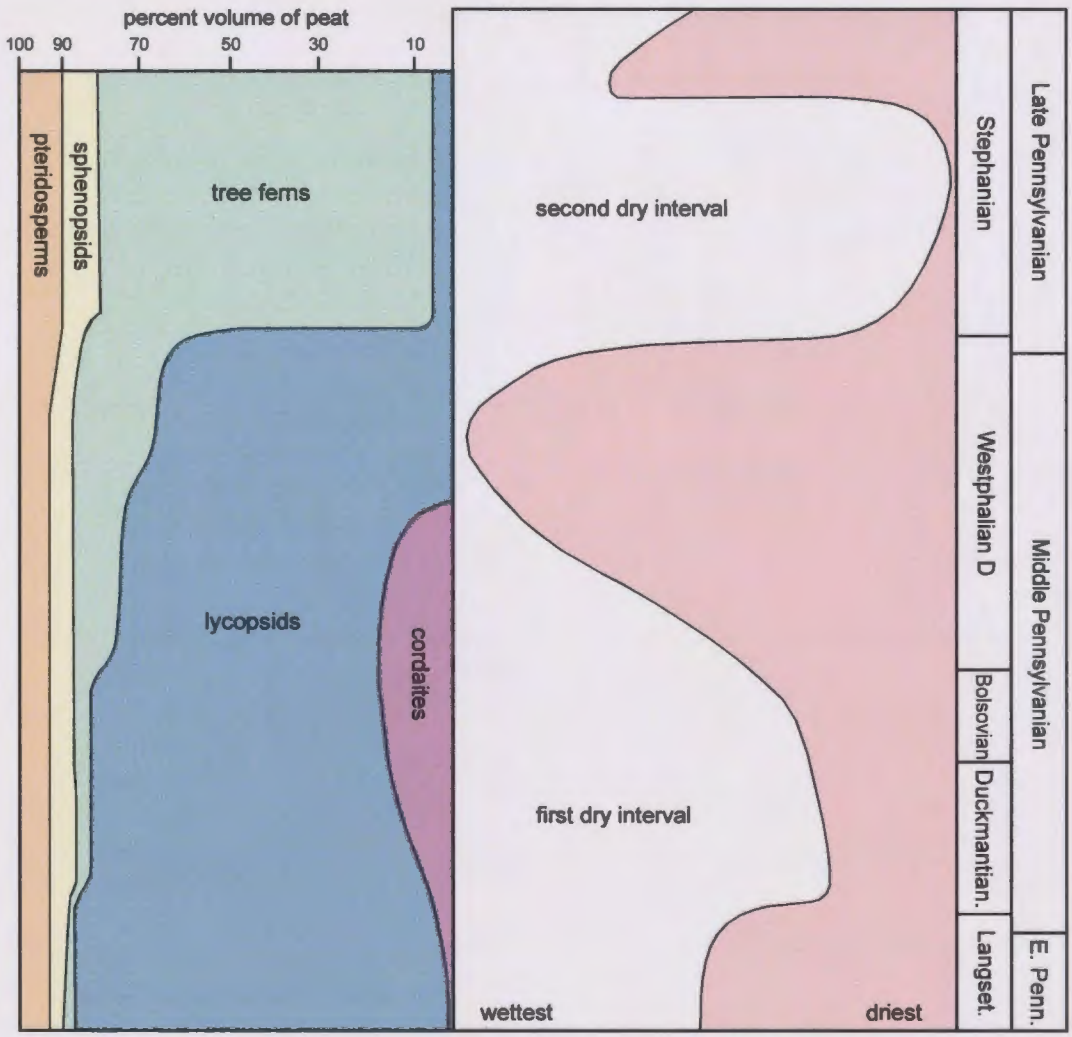


Figure 5.4. Generalized stratigraphic abundance of Pennsylvanian (Upper Carboniferous) coal-swamp vegetation and a relative wetness curve based on sites in midcontinental North America. After Phillips and Peppers (1984), DiMichele et al. (1985) and Phillips et al. (1985).

in floral composition in clastic substrate inhabiting plants (e.g., Pfefferkorn and Thomson 1982; Cleal and Shute 1995). Accordingly, recognition of particular floral associations in the BBA that have previously been documented as the product of either major drying or wetting trends will certainly aid in establishing the age of the locality.

The Duckmantian and Bolsovian climate was apparently dry in comparison with preceding and succeeding stages [Fig. 5.4; see also "first dry interval" of DiMichele et al. (1985) on Fig. 5.2]. This dryness was reflected in changes in floral morphologies and assemblage compositions, including: (i) expansion and migration of cordaiteans, especially of the *Mesoxylon*-type, into peat forming swamps from their more usual well drained, clastic substrate habitats (DiMichele et al. 1985; Phillips et al. 1985; Raymond 1988); and (ii) appearance and expansion of neuropteroids adapted to drier edaphic conditions, including laveineopterids with elongate pinnules (*L. tenuifolia* group) and neuropteroids with flexuous to reticulate venation (e.g., *N. semireticulata*, *Reticulopteris* sp.) (Zodrow and Cleal 1993; Cleal and Shute 1995). Increasingly wetter conditions at the Bolsovian/Westphalian D boundary resulted in the decline and extinction of laveineopterids and neuropteroids with reticulate venation, and the sudden replacement of these forms with neuropterids allied to *N. ovata* (Fig. 5.2; Cleal and Shute 1995).

Comparison of these "paleoecological indicators" with the BBA corroborates earlier conclusions regarding the age of the fossil locality, and helps to establish that the assemblage was thriving during a short interval of the "first dry interval", likely in the upper part of the Bolsovian Stage. In particular, the BBA is: (i) dominated by *Cordaites* spp. foliage, much of which apparently was derived from clastic swamp-fringing plants

(see Chapter 7), and contains abundant large forest-forming trees (*Dadoxylon* sp.) of presumed cordaitean affinity; (ii) characterized by neuropteroids adapted to drier conditions, such as *N. semireticulata*, a form with flexuous veination, and cf. *L. tenuifolia*, a form with markedly long pinnules; and (iii) contains no neuropterids allied to *N. ovata*, which typify Westphalian D assemblages.

Chapter 6 – Depositional Environment

Paleoecological interpretations involving paleobotanical assemblages are much enhanced by a competent understanding of the depositional environment within which the plant communities lived and died. Accordingly, this chapter is a compilation of sedimentological and stratigraphic descriptions of strata from 36 outcrops along Blanche Brook, and provides an interpretation of the environment of deposition of the strata based on the characteristics and distribution of lithofacies and constituent sublithofacies. As previously defined, each sublithofacies represents a unique depositional environment characterized by its sedimentology, stratigraphy (vertical and lateral relationships with other sublithofacies), and plant fossil subassemblage. Stratigraphic sections of the five outcrops that yielded the main macrofloral subassemblages described in this study are given in Figs. 6.1 through 6.6 (see Fig. 1.5 for geographic position of localities).

6.1 Coarse Lithofacies

6.1.1 General Description

Coarse units are entirely contained within the basal portions of large channels, and are gradational with finer grained rocks of the overlying fine lithofacies. Channels have shallowly concave and variably erosive bases that downcut into underlying sediments, usually of the fine lithofacies (Figs. 6.7, 6.17). Strata are ubiquitously trough cross-stratified, and include micaceous sandstones, granular or pebbly sandstones, and pebble conglomerates. Pebbly sandstones and conglomerates are more common near the base of channels, while medium to fine grained sandstones dominate the top. Most rocks

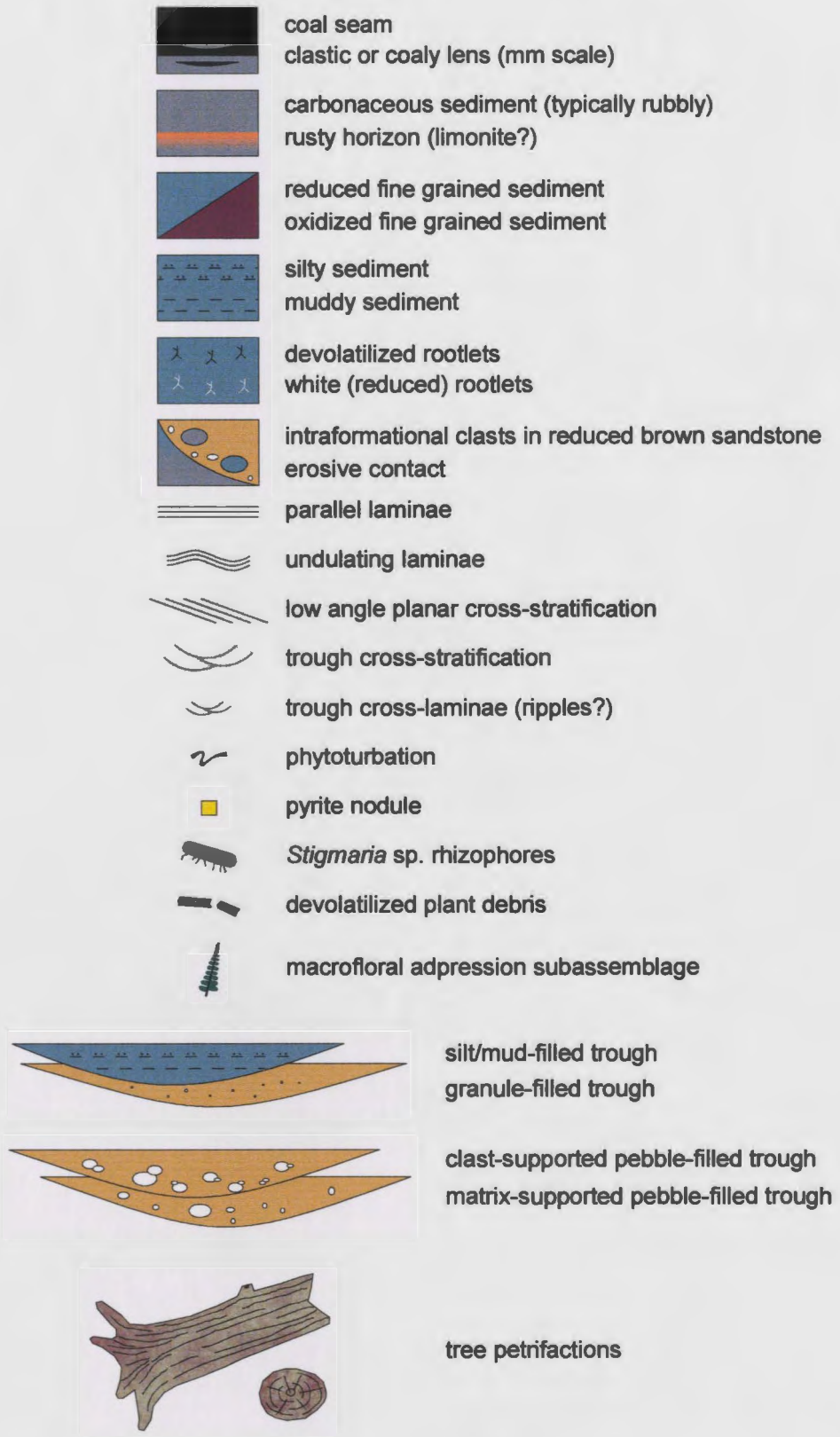


Figure 6.1. Legend for lithostratigraphic sections (Figures 6.2 through 6.6). Note that colours used in figure representative of true rock colours.

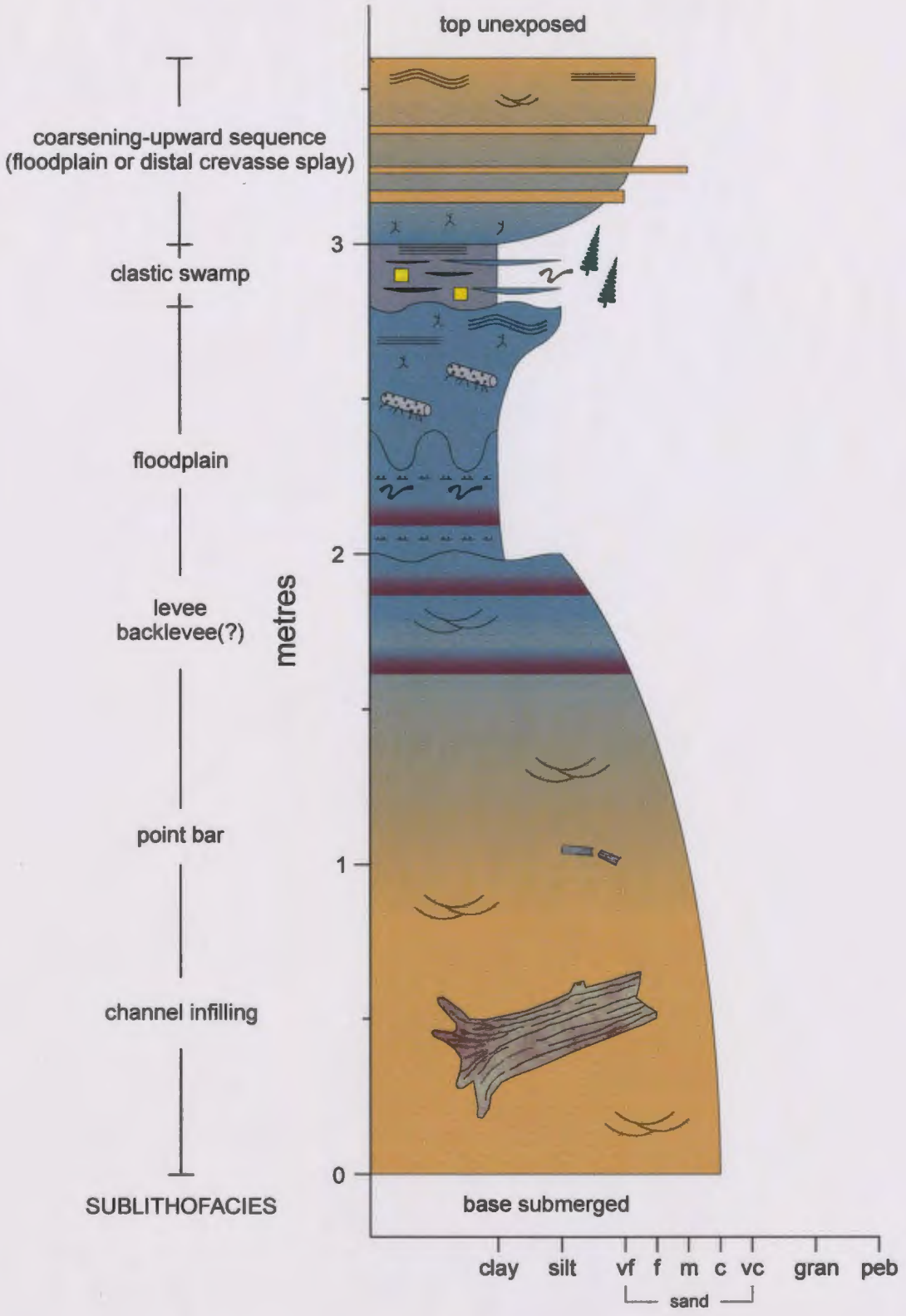


Figure 6.2. Lithostratigraphic section of outcrop at locality BB-14. Note gradational boundaries between some sublithofacies (e.g. point bar and levee/backlevee).

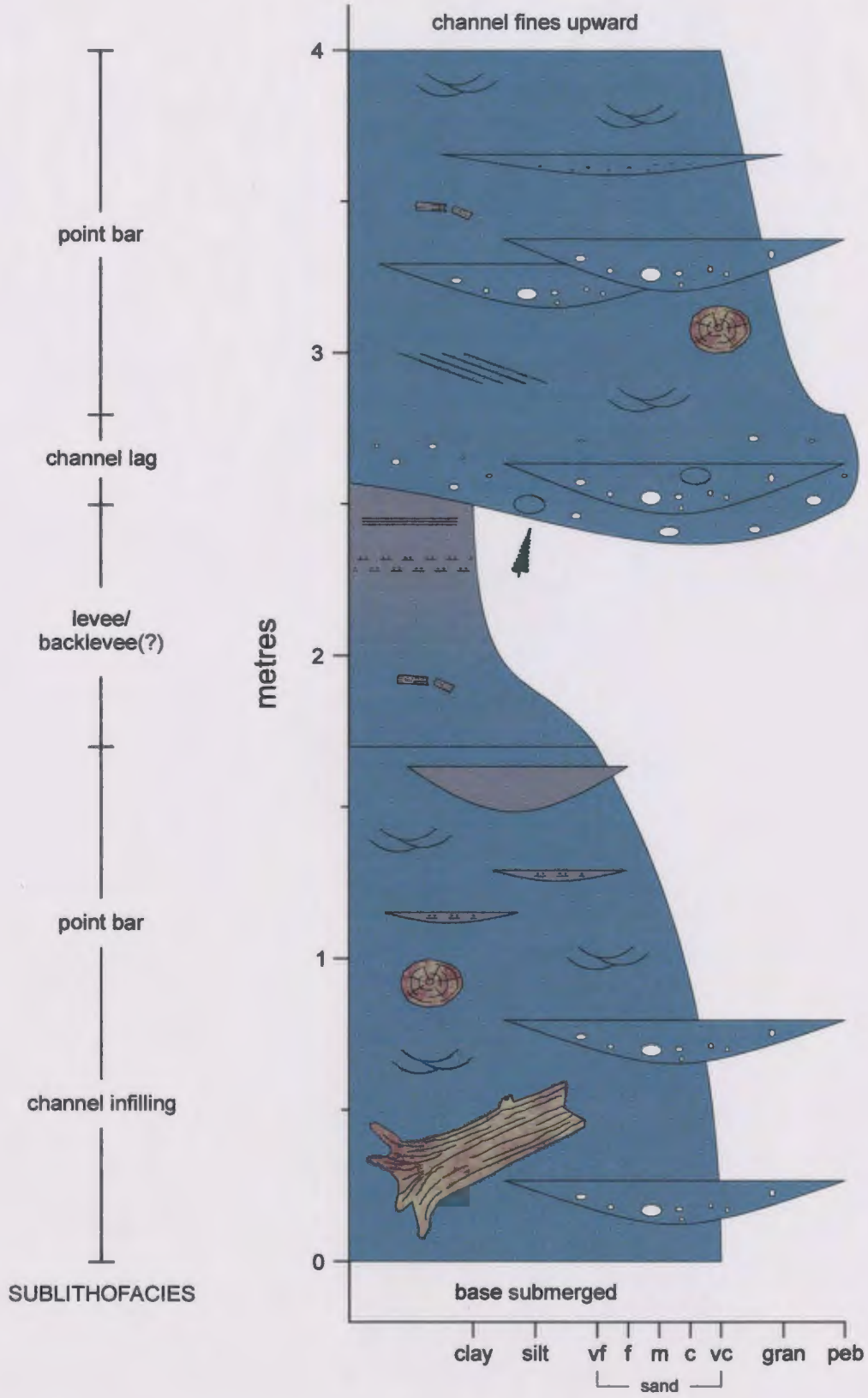


Figure 6.3. Lithostratigraphic section of outcrop at locality BB-19.

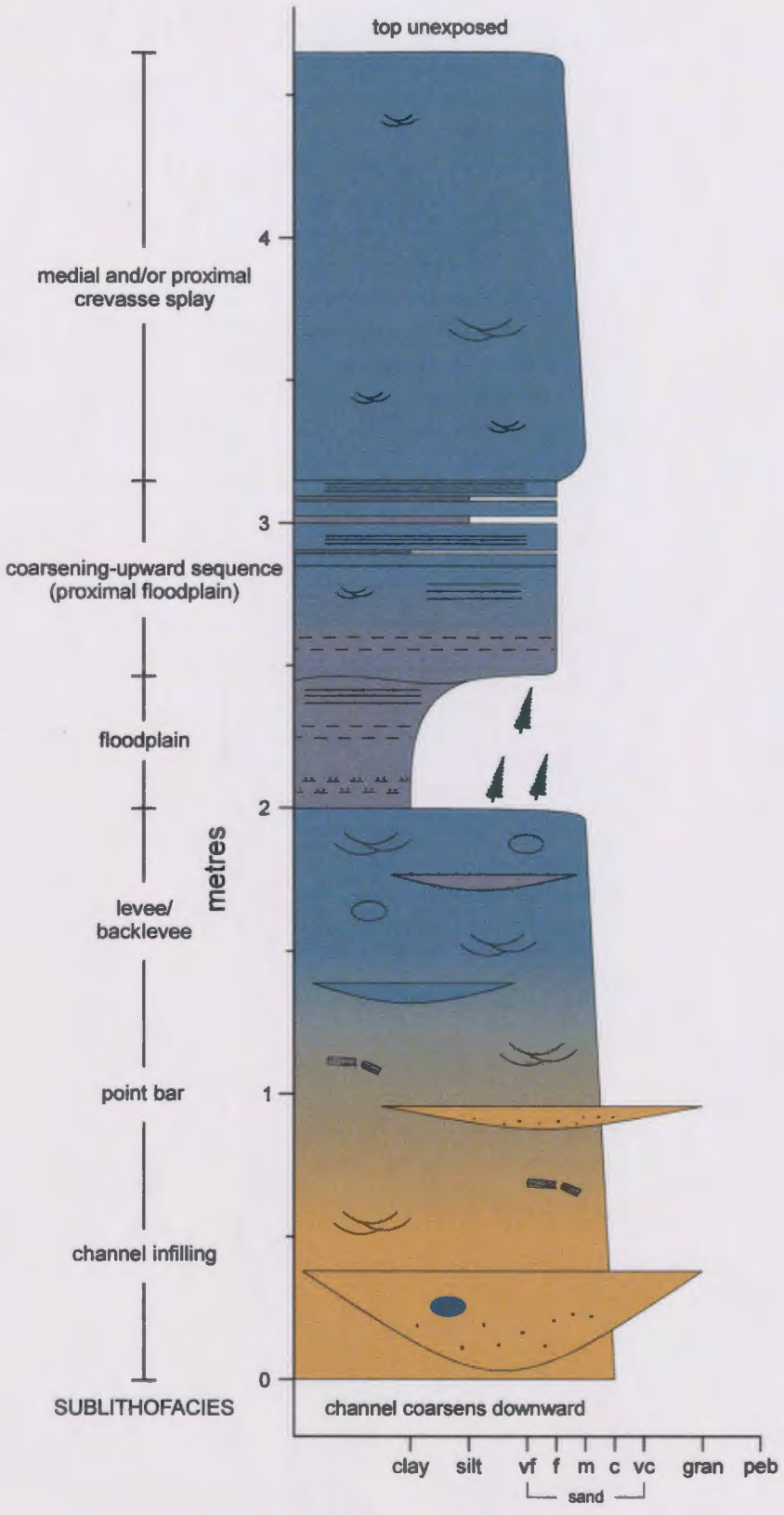


Figure 6.4. Lithostratigraphic section of outcrop at locality BB-25.

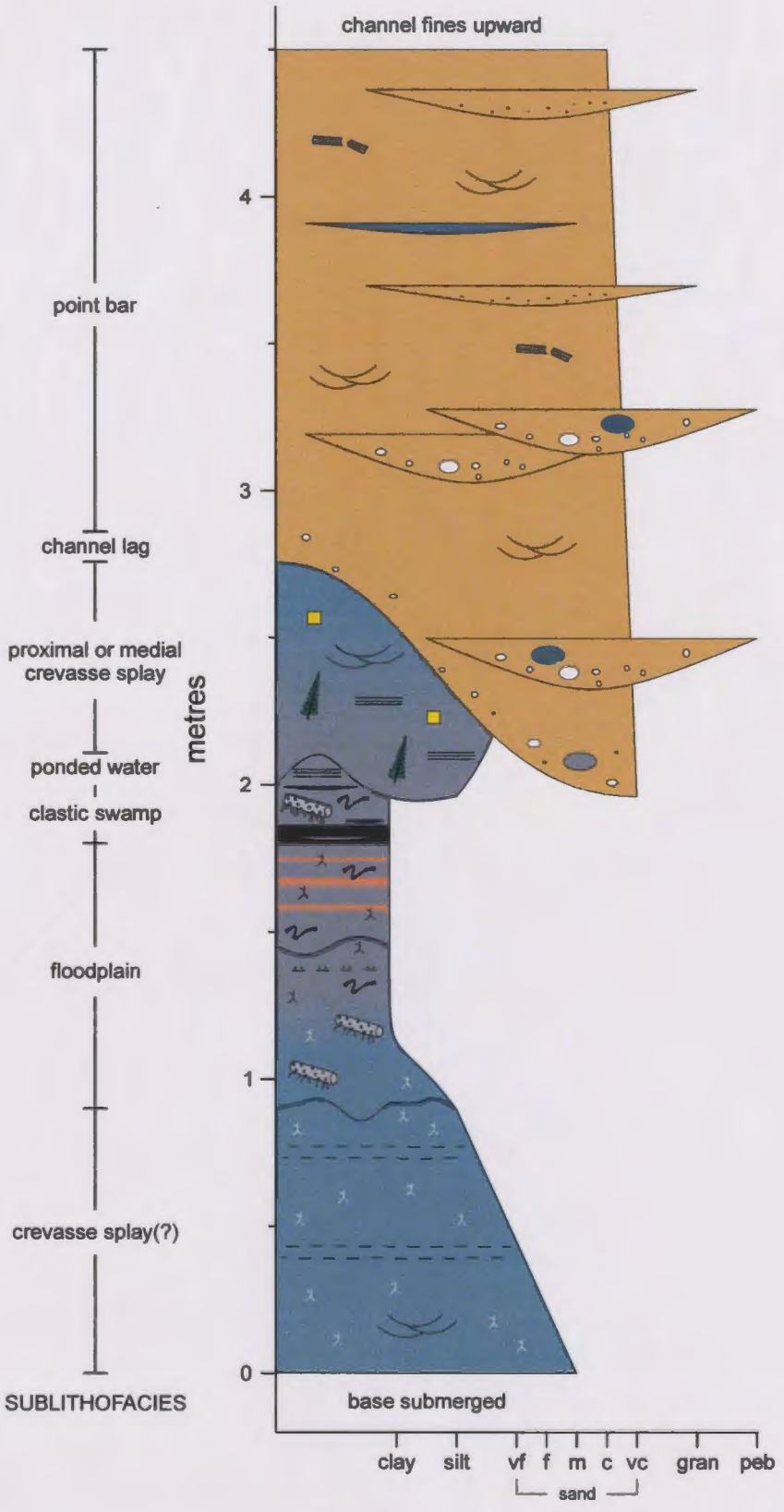


Figure 6.5. Lithostratigraphic section of outcrop at locality BB-30.

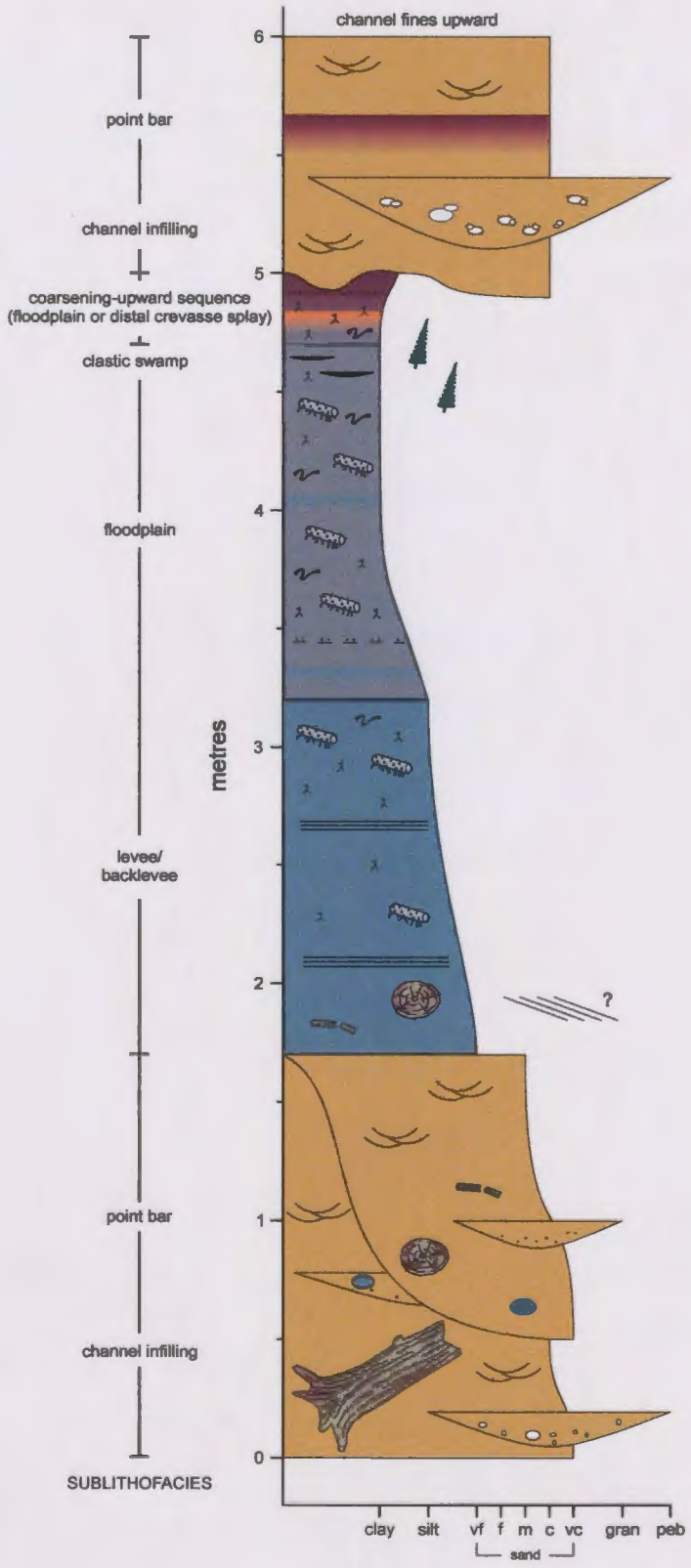


Figure 6.6. Lithostratigraphic section of outcrop at locality BB-32. Note gradational boundaries between some sublithofacies (e.g. levee/backlevee and floodplain).

Figure 6.7. Shallowly concave erosive contact (arrow) between overlying coarse (channel) lithofacies and underlying fine (overbank) lithofacies (coarsening upwards sublithofacies?) at locality BB-29.

are light brown to greenish or bluish grey in color, with purplish to reddish brown coloration being far less common. Brown sandstones and pebbly sandstones are often characterized by a "spotty" appearance due to the presence of scattered, mm- to cm-scale, bleached blotches (Fig. 6.8). The sand component (including conglomerate matrix), which dominates the strata, generally is medium to coarse grained, contains abundant muscovite, and can be categorized as a feldspathic litharenite based on the classification of McBride (1963).

Individual trough cross-strata are defined by cm-scale stringers, lenses or basal lag deposits of granules, extra- or intraformational clasts, or parallel-laminated, greenish

Figure 6.8. Bleached blotches in brown, trough cross-stratified sandstone of the point bar sublithofacies at locality BB-31, with laminae defined by granule concentrations.

to medium grey, micaceous siltstone or very fine sandstone. Troughs (up to 2.0 m thick) occasionally consist entirely of extraformational pebble conglomerates. Laminae within sand-dominated troughs are recognized by concentrations of: granules, micaceous or heavy minerals, comminuted, devolatilized plant fragments, or medium to dark grey (carbonaceous) mudstone.

Extraformational clasts within both the pebbly sandstones and conglomerates are: subangular to rounded, average between 0.7 and 2.5 cm (long diameter), generally are matrix supported, and are predominantly derived from white vein quartz or igneous or metamorphic rocks. Intraformational clasts are: subangular to rounded, 3 to 7 cm in

diameter (exceptionally up to 40 cm), and comprise greenish grey, dark grey (carbonaceous) or (rarely) red to purplish siltstone or mudstone. Devolatilized plant matter typically occurs as comminuted, unidentifiable and randomly oriented fragments making up laminae of trough cross-strata, although elongate stem fragments (some identifiable as *Calamites* sp., *Sigillaria* sp. or *Lepidodendron* sp.) may be oriented parallel to the scour direction of the trough within which they are preserved (Fig. 6.9).

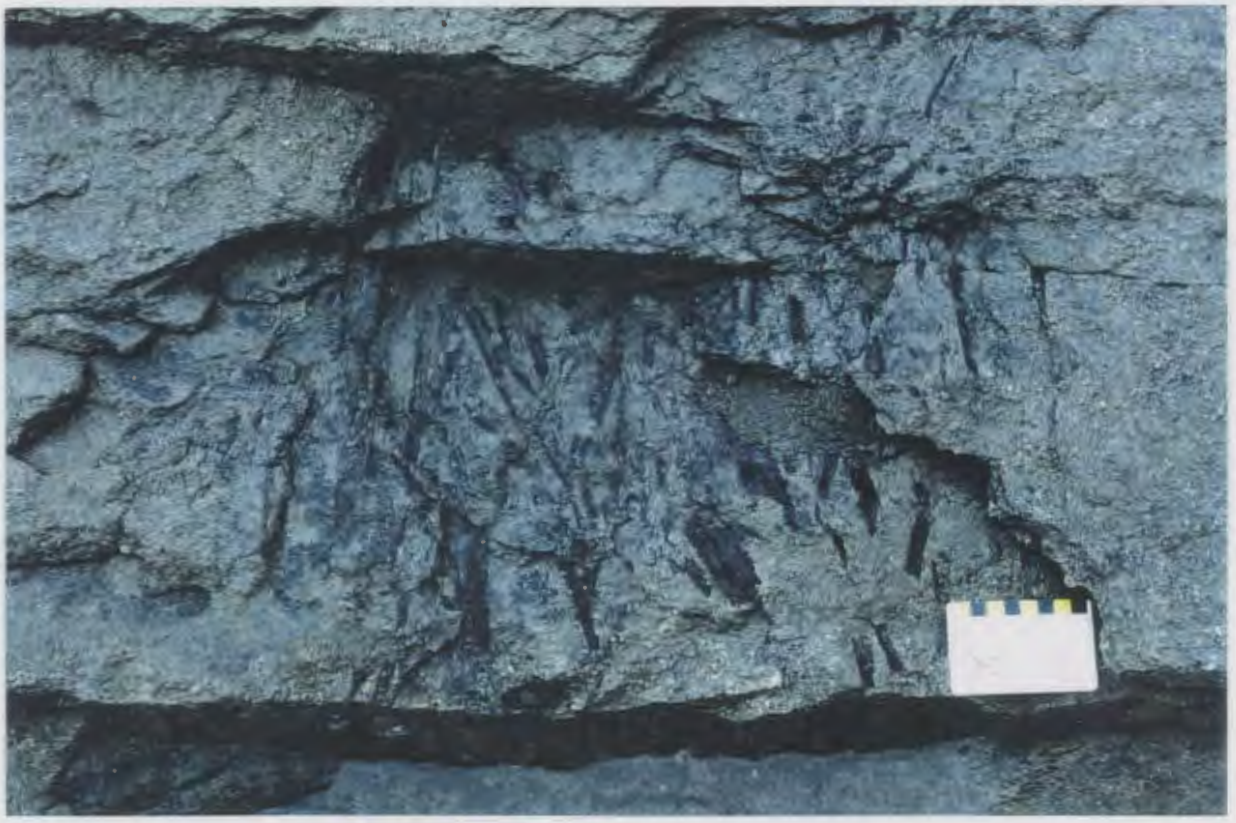


Figure 6.9. Devolatilized stem fragments aligned parallel to trough scour direction in trough cross-stratified sandstone of the point bar sublithofacies. Photograph taken from outcrop along Blanche Brook within Stephenville. Scale bar in cm intervals.

6.1.2 Tree petrifactions

Perhaps the most conspicuous attribute of the coarse lithofacies is the presence of abundant, large volatilized tree petrifactions (Figs. 6.10, 6.11), some reaching up to 4.8 m in length and to 1.9 m in width (measured at base of trunk). Several specimens are essentially uncompressed, cylindrical axes, although the majority of trees are at least partially flattened. Bifurcating roots may be preserved at the base of some fossil logs. Axial fragments typically are preserved unbranched, although most trees have scars along their length that represent the attachment point of previously existing lateral branches.

Figure 6.10. Oblique view of uncompressed, drifted, volatilized tree petrifaction (ca. 4.8 m long) contained within trough cross-stratified, extraformational conglomerate to pebbly sandstone (channel lag sublithofacies) at locality BB-17. Note that the prostrate axis plunges gently away from the slightly elevated root mass. Notebook 17.8 cm long.

Figure 6.11. Uncompressed, upright, drifted, volatilized tree petrifaction preserved within pebbly sandstone of the channel lag sublithofacies at locality BB-23. Notebook 17.8 cm long.

In general, the fossil logs are lying nearly horizontal (dipping between 00 and 27°, ave. 7.3°, $n = 131$) within trough cross-stratified, clast-supported conglomerate, although a single specimen is preserved upright (Fig. 6.11). When subhorizontally oriented trees are preserved with roots, log axes plunge away from the slightly elevated root mass (Fig. 6.10). Occasionally, it can be demonstrated that the long axis of an individual tree fossil is aligned nearly parallel or perpendicular to the scour direction of the trough cross-strata within which it is entombed. At outcrops where tree petrifactions are especially abundant, they are randomly oriented and may occasionally be in contact.

6.1.3 Interpretation

6.1.3.1 Channel lag sublithofacies – On the whole, the coarse lithofacies is interpreted as channel deposits of a mixed-load meandering stream. Trough cross-stratified pebble conglomerates, pebbly and granular sandstones, and associated large volatilized tree petrifactions that directly overlie shallowly concave, erosive surfaces (Fig. 6.7) are interpreted as thin channel lag deposits. The light brown to greenish grey coloration of sediments, which reflects an abundance of diagenetic chlorite containing reduced iron, and presence of pyrite nodules in tree petrifactions (Fig. 3.5.1) implies that reducing conditions were prevalent during deposition of the channel lag sublithofacies.

Trees are thought to represent waterlogged drift that preferentially accumulated at the base of channels within clast-supported conglomerates. Speculatively, loosely aggregated, prostrate, drifted trees that are in contact may represent ancient "log jams". As well, the single vertically disposed stump at locality BB-23 (Fig. 6.11) almost certainly represents transported drift rather than an *in situ* stump in growth position [see criteria of Fritz and Harrison (1985) for differentiating transported tree stumps from those buried in growth position]. The very large size of some petrifactions indicates that channels at least periodically contained very high energy flow capable of entraining and transporting waterlogged trees. Trees probably grew in channel fringing habitats and were added to the fluvial system by channel avulsion, or due to bank undercutting and subsequent collapse that resulted from lateral migration of the meandering stream (Scheihing and Pfefferkorn 1984).

6.1.3.2 Point bar sublithofacies – Successions of progressively finer grained, trough cross-stratified sandstones (Figs. 6.8, 6.9) with relatively fewer granular or pebbly horizons are interpreted as fining upward point bar deposits that accumulated above basal channel lags as a result of channel migration. This is entirely consistent with the simplified fining upward model proposed by Allen (1970) for meandering stream deposits. The light brown to greenish or bluish grey coloration (diagenetic chlorite, see above) and abundance of devolatilized, comminuted plant debris in the deposits suggests that sediment pore waters were reducing (-Eh) during accumulation. Bleached spots (Fig. 6.8) within light brown sandstones have been interpreted as reduction spots that may have formed in response to anaerobic decay of small particles of organic matter within the sandstone (Retallack 1990). Although purplish to reddish brown point bar deposits are comparatively scarce within the section, their presence indicates that accumulation occasionally occurred under oxidizing, well drained conditions, probably during intervals when the water table was comparatively low.

The abundance of trough cross-strata that either are entirely filled with or contain mudstone to very fine sandstone laminae indicates that disequilibrium existed between the aqueous flow and sediment surface (Fielding 1986). As such, deposition likely occurred in a regime of variable discharge, perhaps influenced by frequent (flash) flooding and/or bank instability.

The marked amount of intraformational clasts in this sublithofacies indicates that bank undercutting and collapse of partially lithified overbank strata into the migrating channel was a very common event. The abundance of devolatilized plant remains

indicates that channel fringing habitats laterally adjacent to (and being eroded by) the channel were fully capable of supporting vegetation. The fragmented and unidentifiable nature of most debris indicates that it was mechanically abraded during transport. Plants might have entered the channel system when banks collapsed, or alternatively, smaller fragments may have been blown into the stream (Ferguson 1985; Spicer and Greer 1986; Gastaldo 1988).

6.1.4 Paleocurrent Data

The combined data from tree petrifaction orientations, trough scour directions, extraformational clast and matrix composition, and the assumed paleotopographical setting all evince a general paleoflow trend from the northeast towards the southwest. A composite rose diagram (Fig. 1.5) of scour directions measured from trough cross-strata demonstrates highly variable paleocurrents throughout the succession, although a predominant northeast or southwest paleoflow direction is evident (vector mean = 232.2°). Conversely, down dip lineation trends measured from tree petrifactions illustrates a strong preferential southeast orientation, with a weaker northeast-southwest alignment (Fig. 1.5). Hence, although many trees are oriented parallel to the dominant paleoflow direction (as determined by trough scour orientations), many of the trees are oriented essentially perpendicular to the presumed paleoflow (cf. Fritz and Harrison 1985).

According to L. Quinn (personal communication, June 1994), the majority of extraformational pebbles likely were derived from Grenvillian (Precambrian) basement (see also Knight 1983; Solomon 1986), which comprises igneous and metamorphic rocks

that are presently exposed east and northeast of Blanche Brook (Williams 1985; Williams and Cawood 1989). This interpretation is supported by the prevalence of muscovite within most sediments, which implies that at least part of the source terrain comprised metamorphic rocks. These paleocurrent and provenance data are consistent with the postulation that strata were deposited in a narrow, northeast-southwest trending subbasin that was open to the southwest but otherwise confined by paleotopographical highs to the northwest (Table Mountain), northeast, and southeast (Indian Head Promontory) (Fig. 1.4). Streams would have flowed and transported sediment southwestward towards topographically lower areas of the Maritimes Basin (see Gibling et al. 1992).

6.2 Fine (Overbank) Lithofacies

6.2.1 General Description

The fine lithofacies includes a diverse assemblage of fine grained siliciclastics that (without exception) are gradational with rocks of the underlying coarse lithofacies. Essentially then, these strata represent the culmination of fining upward channel sequences that were in turn erosively truncated during avulsion by a succeeding channel (Figs. 6.7, 6.12, 6.17). A complete gradation exists from medium grained sandstone to siltstone to mudstone, with coal horizons being rare. The majority of strata are either greenish to bluish grey (abundant diagenetic chlorite, see above) or medium to dark grey (when carbonaceous), while reddish to purplish brown strata are less common.

The fining upward succession can be generalized as an upward decrease in grain size from micaceous, rooted, medium or fine grained sandstones to rubbly, phytoturbated and/or mottled mudstones. When this sequence is dominated by greyish strata (which is

Figure 6.12. Outcrop at locality BB-30, showing typical succession of sublithofacies from levee/backlevee(?) (l)→floodplain (f)→clastic swamp (s) with thin coal seam (arrow)→crevasse splay (cs)→succeeding channel (ch). Note the crevasse splay deposit, which has a sharp, slightly erosive base, is in turn erosively truncated by overlying channel. Backpack ca. 50 cm tall.

most commonly the case), carbonaceous mudstones in the section often contain mm-thick coal lenses, frequently contain fragmentary but very well preserved floral adpressions, may be stained by iron oxides, and may be associated with thin (3.5 to 12 cm, ave. 4 to 5 cm), laterally discontinuous, high ash (Hyde et al. 1991) coal seams (Figs. 6.12, 6.13) that may be split by carbonaceous mudstone horizons (Solomon and Hyde 1985).

Figure 6.13. Outcrop at locality BB-14, with succession of sublithofacies from floodplain (f)→clastic swamp→coarsening upwards unit (cu). Grey floodplain deposits contain abundant slickensides and stigmarian rootlets. Very dark grey, carbonaceous shale containing mm-scale coaly horizons characterizes the clastic swamp sublithofacies, which is in turn gradationally overlain by the coarsening upwards sublithofacies. Scale bar in cm intervals.

Mudstones and coal-bearing rocks within the generalized fining upward successions are subsequently overlain either gradationally or sharply by coarsening upward units of micaceous siltstone to fine sandstone. Units with gradational bases (Fig. 6.13) occasionally have parallel, wavy, trough and/or planar cross-laminations composed of comminuted plant debris, reddish or dark grey (carbonaceous) mudstone, or coarse grained sandstone. Conversely, sharp-based successions (Fig. 6.12) may exhibit faint

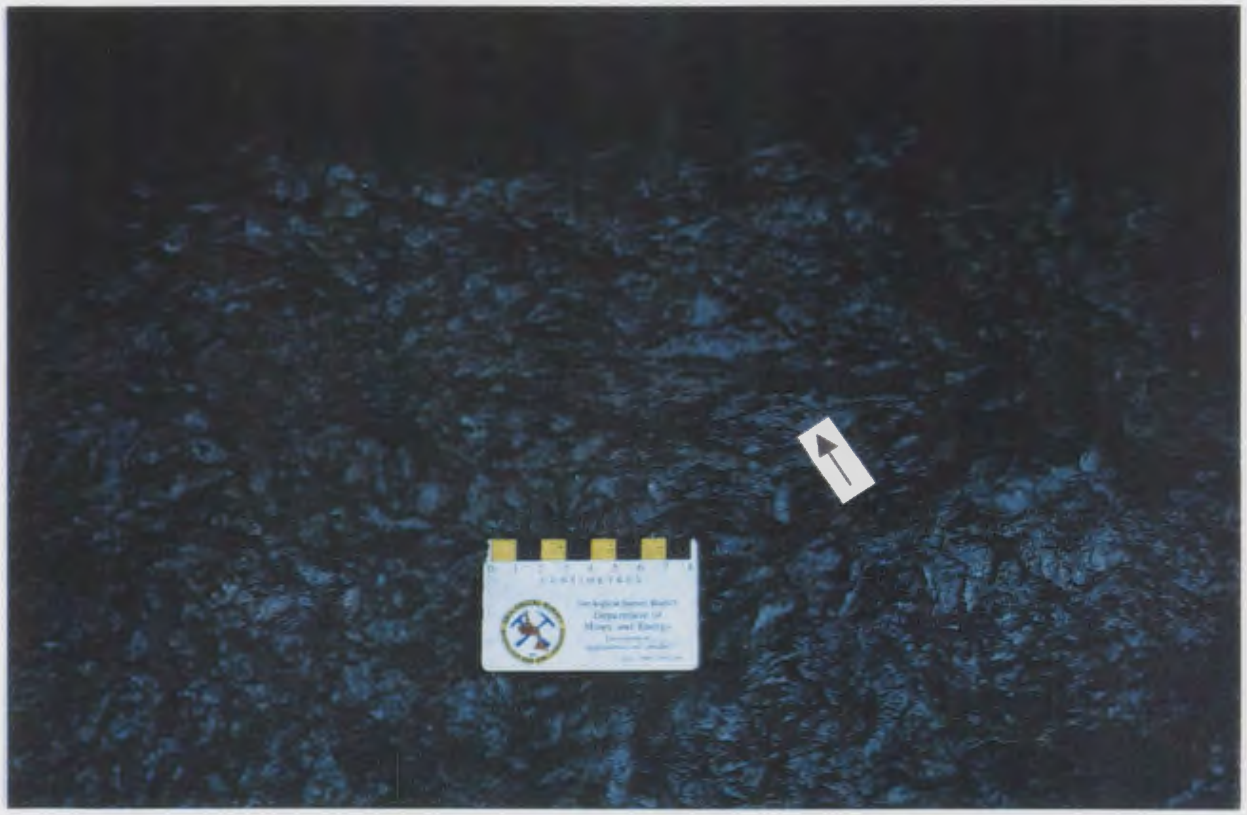


Figure 6.14. Large *Stigmaria* sp. rhizophore (see circular, helically arranged surface scars at arrow) with attached lateral organs within rubbly, heavily phytoturbated, grey floodplain sublithofacies which is essentially devoid of primary sedimentary structures. Locality BB-30.

trough cross-stratification, and may contain well preserved plant fossils along with mm-scale pyrite nodules.

Perhaps the most marked characteristic of the fine lithofacies is the abundance of beds containing *in situ* plant roots. The majority of root-bearing rocks are characterized by a rubbly or blocky texture with abundant slickensided surfaces, and otherwise lack sedimentary structures (Figs. 6.13, 6.14). Within greyish units, mm-scale rootlets are preserved as unidentifiable, black, devolatilized adpressions or white, branching traces. Conversely, rootlets in reddish, phytoturbated mudrocks frequently are abundant but

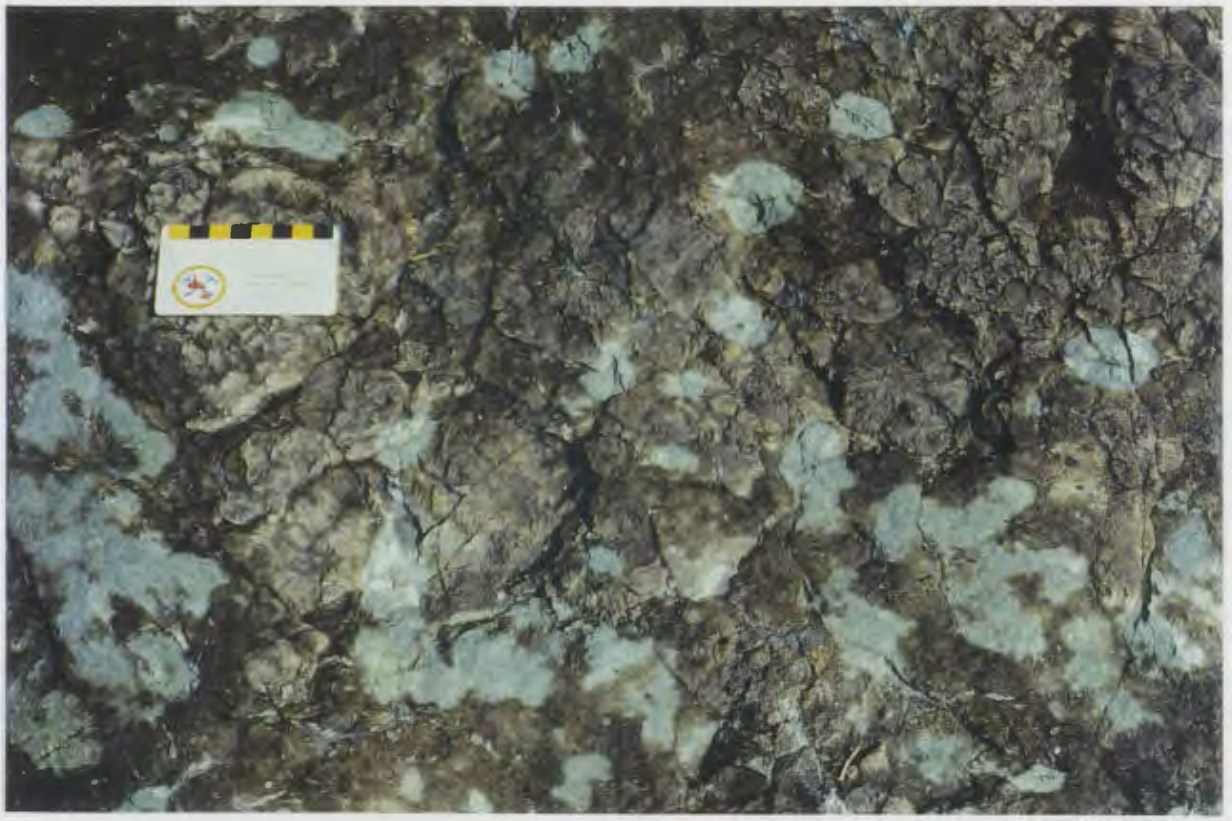


Figure 6.15. Bluish grey blotches (reduction spots) cored by devolatilized organic matter (remnants of plant rootlets) within reddish floodplain sublithofacies at locality BB-5.

poorly preserved as decarbonized traces. *Stigmaria* sp. rhizophores with attached lateral organs (Fig. 6.14) are especially common in greenish to bluish grey mudstones or muddy siltstones associated with coaly horizons and/or plant-bearing mudstones.

Reddish, phytoturbated mudstones frequently are mottled by mm- to cm-scale, greenish to bluish grey, irregularly shaped blotches that typically have a core of devolatilized organic matter (Fig. 6.15). These blotches may be confined to a single bedding plane but often crosscut bedding. Although rare, some red mudstones contain a network of circular and irregular, vertical fractures infilled with calcium(?) carbonate (Fig. 6.16). Bluish grey mudstones intimately associated with red mudstones may

Figure 6.16. Network of carbonate ($CaCO_3$?)-infilled, circular and vertical fractures in reddish floodplain deposits at locality BB-5. Fractures with circular outline (arrows) may represent replaced plant stems consisting of hollow piths surrounded by thin, woody axis (cf. *Calamites*(?) sp.).

contain semicircular, cm-scale concretions comprising radiating, greyish, calcareous mudstone (Fig. 6.17).

6.2.2 Interpretation

Strata of the fine lithofacies are interpreted as overbank deposits that accumulated laterally adjacent to the active meandering stream channel. Deposition in overbank areas occurred when sediment-laden floodwaters either incised or rose above channel banks. In general, more coarsely grained deposits formed proximal to the channel (e.g., levee/backlevees or crevasse splays), while mudstones and coal-bearing rocks developed

Figure 6.17. Radiating, calcareous(?) mudstone concretions within bluish grey floodplain sublithofacies at locality BB-5, possibly representing ferruginous or ferralitic paleosol (see text). Floodplain deposits erosively truncated by channel lag sublithofacies of succeeding channel. Scale bar in cm-intervals.

in more distal positions (e.g., floodplains or clastic swamps).

6.2.2.1 Levee/backlevee sublithofacies – Phytoturbated, rooted, rubbly mudstones (with uncommon *Stigmaria* spp. in grey sediments) and parallel-laminated siltstones to very fine sandstones that directly overlie deposits of the point bar sublithofacies are interpreted as levee/backlevee deposits that formed along channel margins. Sediments of this sublithofacies are conspicuously thin and very poorly developed within the succession, which seems to indicate that channel banks were not elevated very far above the water table. Significantly, this also implies that water flow

probably was poorly confined by channel margins. It is apparent from the limited development of levees that much of the fine sandstone/siltstone component comprising typical levee deposits (Fielding 1984b; Collinson 1996) was removed from the channel system before it could accumulate on levees. Instead, it is postulated that these sediments were preferentially deposited in crevasse splay systems, thus effectively bypassing rather than adding to levee deposits.

The presence of roots and phytoturbation indicates that levee tops and flanks were well vegetated. Levee/back levee deposits are gradational with (and very difficult to differentiate from) vertically and laterally adjacent floodplain deposits.

6.2.2.2 Floodplain sublithofacies – This sublithofacies is characterized by rubbly, rooted and heavily phytoturbated mudstones otherwise devoid of sedimentary structures. Most strata compare very closely with the "simple alluvial paleosols" of Kraus and Asland (1993). Strata accumulated by vertical accretion when sediment laden floodwaters overtopped levees – sands and silts would have been deposited close to the channel, while clays would have settled from suspension in more distal parts of the floodplain.

Grey floodplain deposits may be carbonaceous and pyritiferous (now oxidized to iron oxides), may contain well preserved but quite fragmentary (partly allochthonous?) macrofloral subassemblages, and generally contain abundant *in situ* stigmarian rhizophores (Fig. 6.14). It is interpreted that these grey strata were permanently waterlogged and accumulated under reducing conditions. This assumption is supported by the presence of a bleached, rubbly mudstone horizon directly beneath carbonaceous,

coaly mudstones (clastic swamp sublithofacies) at locality BB-29. This bleached mudstone is similar to the "gley paleosol" described by Kraus and Aslan (1993), which apparently indicates soil formation in very poorly drained, reducing, hydromorphic conditions where the water table is permanently high (Kraus and Aslan 1993; Collinson 1996). Blocky or rubbly textures (Fig. 6.13) and slickensides (Fig. 6.12) may be partially attributed to alternating wet and dry conditions that resulted from inconsistent inundation by floodwaters (Gustavson 1991). This interpretation is substantiated by recent paleoclimatic work in the Maritimes Basin by Chandler (1998), who concluded that the climate in the region during the Westphalian was tropical and seasonal with a pronounced dry season.

Phytoturbated, mottled mudstones characterized by a reddish coloration and virtual absence of plant fossils very likely accumulated under comparatively well drained and oxidizing (+Eh) edaphic conditions. Carbonate-infilled vertical fractures with circular outlines within red mudstones (Fig. 6.16) are interpreted as the remnants of plant stems (Klappa 1980) with hollow piths surrounded by a thin layer of woody(?) tissue (perhaps cf. *Calamites* sp.). Similarly, greyish blotches containing vertical, devolatilized cores within red, heavily bioturbated mudstones (Fig. 6.15) almost certainly represent root traces (Retallack 1990), and indicate that even subaerially exposed floodplains were capable of supporting prolific plant growth. Calcareous(?) concretion-bearing, bluish grey mudstones (Fig. 6.17) that directly overlie redbeds likely represent ferruginous or ferralitic paleosols (Duchaufour 1982), which apparently are indicative of a fluctuating water table and warm climatic conditions (Duchaufour 1982; Collinson 1996).

6.2.2.3 Clastic swamp sublithofacies – This sublithofacies is characterized by thin coal seams (Fig. 6.12), and by thoroughly phytoturbated, medium to dark grey (carbonaceous) mudstones (Fig. 6.13) that generally contain mm-scale coaly horizons, small pyrite nodules, and very well preserved but fragmentary plant adpressions. Clastic swamps seemingly developed in the topographically lowest areas on the distal side of and laterally adjacent to floodplains; sedimentological (and ecological) gradients likely existed between clastic swamps and the distal portions of floodplains that flanked them.

Peats record the prolific growth and accumulation of vegetable matter under reducing, acidic and periodically standing water at or very near the level of a permanently high water table, especially when sediment suspended in floodwaters was excluded by the baffling effect of plants growing around the swamp margin (Fielding 1984a; McCabe 1984; Collinson 1996). However, the rarity and both spatially and temporally restricted nature of coal seams along Blanche Brook indicates that peats developed under conditions that were far from ideal. The fact that coals are high in ash, very thin, and may be split by carbonaceous mudstone horizons strongly indicates that nutrient-rich floodwaters frequently incurred on the swamp, which hindered and (soon after inception) choked off peat development. Likewise, carbonaceous mudstones containing only thin coal seams likely record clastic swamp deposition in which the rate of sediment introduction far exceeded the accumulation rate of plant matter. It is envisioned that mud settled out of suspension after being introduced to the clastic swamp when far reaching floodwaters containing abundant suspended sediment overtopped levees. Silty,

fossiliferous horizons within the clastic swamp sublithofacies at BB-14 very likely record exceptional and more vigorous flood events.

The upper cms of clastic swamp deposits at localities BB-14 (Figs. 6.2, 6.13) and BB-30 (Figs. 6.5, 6.12) both constitute finely laminated, fissile, unrooted, highly carbonaceous shales. It is interpreted that these laminated and unbioturbated sediments formed by slow settling of suspended sediment within small, stagnant (anoxic) ponds (Fielding 1984b; Solomon and Hyde 1985; Solomon 1986) that were fairly shallow but just deep enough to impede the growth of most plants. So, although it is equivocal whether or not clastic swamps were permanently submerged, it is evident that the final developmental stages of some swamps were characterized by standing water that probably drowned most peat-forming vegetation.

6.2.2.4 Crevasse splay sublithofacies – Coarsening upward successions with sharp bases (Fig. 6.12) are interpreted as proximal or medial crevasse splays. These deposits formed during flood events when channel levees were breached and a slurry of sediment-laden water was transported onto the floodplain via a crevasse channel. The sharp (perhaps slightly erosive) bases, presence of trough cross-stratification, and variable orientation of macrofloral remains within greyish deposits attest to the rapidity and energy of sedimentation. However, the excellent preservation and comparatively less fragmented nature of the plant fossils within this sublithofacies may indicate a minimal distance of transport. Although plants may have been sampled from anywhere between the (breached) levee and their final resting place atop floodplain or clastic swamp deposits, studies of modern coal swamp analogues (Gastaldo et al. 1987; Scheihing and

Pfefferkorn 1984) suggest that much of the debris was derived from vegetation growing on levees upstream from the breach site. The grey color, excellent preservation of adpressed macroflora, and presence of pyrite nodules provides evidence that most crevasse splays were deposited under reducing conditions.

6.2.2.5 Coarsening upwards sublithofacies – Siltstone and very fine sandstone-dominated, coarsening upward successions that gradationally overlie floodplain or clastic swamp deposits (Fig. 6.13) are interpreted as either small deltas that formed at the distal end of crevasse splays that encroached and eventually infilled clastic swamps, or simply represent comparatively coarse grained floodplain deposits. The increase in grain size attests to the gradual approach of an active channel and/or associated crevasse splays due to channel migration across the floodplain. The paucity of rootlets or bioturbation within these successions indicates that sedimentation was constant enough that plants were unable to colonize the exposed sediment surface. Exceptional flood events may be represented in the upper part of these coarsening upward sequences by fine to medium grained sandstone laminae and beds within siltstones, and by trough cross-stratified sandstones.

6.2.3 Implications of Crevasse Splay and Coarsening Upwards Sublithofacies

Coarsening upward successions, whether with gradational or sharp lower boundaries, generally are erosively truncated by channel lag deposits of a succeeding channel (Figs. 6.7, 6.12) rather than being overlain by finer floodplain deposits. According to Fielding (1984a, p. 920), this implies that channel avulsion was common and at least partly initiated by crevassing of channel banks. However, the small thickness

of avulsion-related deposits between successive, downcutting channel sandstones suggests that active channels had limited area for lateral migration, and alludes to the fact that the floodplain was relatively narrow (Bridge and Leeder 1979; Collinson 1996).

6.3 Summary of Depositional Environment

Strata from along Blanche Brook are interpreted as the deposits of relatively coarse grained, mixed-load, meandering streams that flowed in a general southwesterly direction across a narrow floodplain that occupied a northeast-southwest trending subbasin in the northern extreme of the Bay St. George Basin (Figs. 1.4; 6.18). Evidence suggests that channel waters were rather poorly confined and thus frequently overtopped or breached channel levees during flooding events. Recurrent incursions of sediment-laden floodwaters onto the floodplain occurred in part because: (i) channel bounding levees seemingly were poorly developed and of low elevation; (ii) the avulsion belt through which streams flowed was very narrow and thus in proximity to the floodplain; and (iii) repeated crevassing of channel banks initiated channel avulsion and lateral migration.

The majority of overbank strata, which accumulated by vertical accretion when floodwaters overtopped levees, were deposited under waterlogged, reducing conditions at or very near the water table level (which generally was quite high). However, red colored rocks within both the coarse and fine lithofacies indicate that some strata were deposited above the water table where they were well drained and heavily oxidized, suggesting that the rate of basin subsidence(?) and/or water table was fluctuating. The prevalence of rootlets and phytoturbation in levee/backlevee and floodplain deposits,

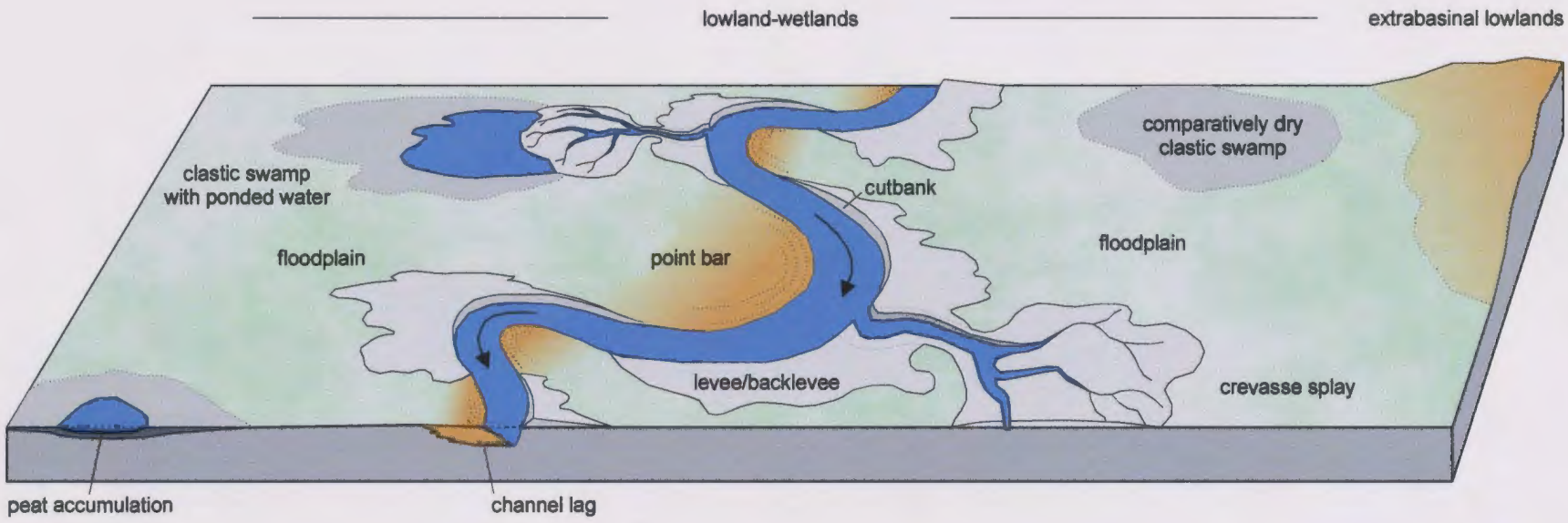


Figure 6.18. Hypothetical reconstruction of meandering stream depositional environment as interpreted from fossil-bearing and associated strata along Blanche Brook. Note that distance between extrabasinal lowlands and lowland-wetlands is not to scale.

regardless of whether waterlogged or well drained, indicates that paleosols supported a profusion of plants. The vast majority of plant fossils and debris very likely were transported some distance via water or wind before deposition.

Distal and topographically lowest parts of the floodplain were occupied by clastic swamps within which peat development was strongly influenced and laterally and temporally restricted by frequent incursions of nutrient-rich floodwaters. As active channels migrated and approached the swamps, peat development was effectively choked off by crevasse splay deposits or more proximal (i.e., increasingly more coarse grained) floodplain sediments. Alternatively, plants inhabiting the clastic swamp may have been drowned by shallow, stagnant water that ponded during late stages of swamp development. Regardless of the reason(s) for the demise of the clastic swamps, observations from this study corroborate conclusions of Solomon and Hyde (1985) that peat within clastic swamps of the Barachois Group developed under intrinsically unfavorable conditions, and either were drowned by standing water or smothered by sediment encroachment shortly after inception.

Chapter 7 – Paleoecology

7.1 Definition of Floral Habitats

During the Late Carboniferous (Westphalian and Stephanian Epochs), terrestrial environments of Euramerica were characterized by extensive topographically low-lying alluvial, deltaic and coastal plains surrounded by comparatively elevated slopes. The poorly drained plains, or "lowland-wetlands", were basinal areas of net deposition, and included a variety of edaphically distinct depositional environments, each of which provided an ecologically distinct habitat for the establishment and growth of diverse and unique floral assemblages. In the present study, the lowland-wetlands are defined as encompassing all of the sublithofacies described in Chapter 6, including channel sediments, levee/backlevee complexes, floodplains, and clastic swamps (Fig. 6.18).

The narrow alluvial plain at Blanche Brook probably was surrounded by topographically higher regions of net erosion that may have sustained edaphically restricted floral assemblages. Slopes of gentle to moderate grade that likely existed directly adjacent to the depositional plain are termed "extrabasinal lowlands" (Fig. 6.18; *sensu* Pfefferkorn 1980), while the term "extrabasinal uplands" (*sensu* Pfefferkorn 1980, *non* Chaloner 1958) is restricted to mountainous terrain with steep, rocky slopes; Table Mountain and the Indian Head Promontory presumably represent the erosional remnants of these Late Carboniferous mountains.

7.2 Interpretation of Paleoecology of Blanche Brook Assemblage

The effects of taphonomy, particularly biostratinomic factors, have often destroyed many of the indicators required to make conclusive deductions about the original paleoecological and paleoenvironmental settings of plant fossil communities. As a consequence, formulation of an accurate paleoenvironmental model for Blanche Brook must rely heavily on homotaxial analogies with paleobiological and paleoecological preferences and amplitudes that have been previously interpreted for representatives of the five main plant groups found at the site (lycopsids, sphenopsids, ferns, pteridosperms and cordaites). The following discussion will also consider the influence of broad fluctuations in plant dominance and diversity patterns that occurred throughout the Late Carboniferous as a result of changing climatic conditions and consequent speciation and extinctions (Fig. 5.4). As well, the paleobotanical affinities of miospores recovered by Hyde et al. (1991) from coal seams at localities BB-29 and BB-30 (Fig. 7.1) will be incorporated into construction of a working paleoenvironmental model for the BBA.

7.2.1 Lycopsids

Arborescent lycopsids centered in clastic-influenced habitats were relatively short lived, monocarpic plants with a basic pole-type architecture and a leaf- and cone-bearing, forked or dendritic crown that typically grew for reproductive purposes (rather than for light capture) just prior to death of the plant (DiMichele and Phillips 1985; DiMichele et al. 1992; Phillips and DiMichele 1992). Other polycarpic (i.e., continuous reproduction) forms had rows of deciduous, cone-bearing lateral branches along the length of the trunk.

Miospore	Paleobotanical Affinity	Authority	Reference Source(s)*
Arborescent Lycopsids			
Apiculatisporites spp.[c] (=*Cappospontes* spp.)	*Diaphorodendron*	DiMichele (1985)	Phillips et al. (1985); Phillips (1979)
Crassispora kosankei[c]	*Sigillaria*	Chaloner (1953)	Bartram (1987)
Lycospora pusilla[c]	*Lepidodendron hickii*	Willard (1989)	Willard (1989)
Lycospora noctuina[a]	*Lepidodendron* (?)	Chaloner (1953)	Smith (1962)
	Lepidophloios (?)	DiMichele (1979)	Phillips et al. (1985)
	Paralycopodites (?)	DiMichele (1980)	Bartram (1987)
Herbaceous Lycopsids			
Cirratriradites saturni[c]	*Selaginellites*	Hoskins and Abbott (1956)	Bartram (1987)
Endosporites spp.[c]	*Chalonera*	Pigg and Rothwell (1983)	Bartram (1987)
Ferns			
Acanthotriletes sp.[b]	Fern (Filicales)	Good (1979) Millay and Taylor (1982)	Traverse (1988)
Convolutispora sp.[a]	Tree fern (Marattiales)	Laveine (1969)	Traverse (1988)
Cyclogranisporites spp(?).[c]	Various ferns	Remy and Remy (1955)	Smith (1962)
Dictyotriletes sp.[b, d]	Fern (Filicales)	Hamer and Rothwell (1983); Scott et al. (1985)	Traverse (1988)
Granulatisporites sp.[b]	Fern (Filicales)	Scott (1978); Good (1979)	Traverse (1988)
Laevigatosporites spp.[c]	Tree fern (Marattiales)	Laveine (1969)	Traverse (1988)
Leiotriletes sp.[b]	Various ferns	Knox (1938); Mamay (1950); Remy and Remy (1960)	Smith (1962)
Lophotriletes spp(?).[c]	Fern (Filicales)	Good (1979)	Traverse (1988)
Punctatosporites spp.[c]	Tree fern (Marattiales)	Laveine (1969); Lesnikowska and Millay (1985)	Traverse (1988)
Raistrickia spp.[c]	Various ferns	Remy and Remy (1955); Laveine (1969); Mickle (1980)	Smith (1962) Traverse (1988)
Torispora securis[c]	Tree fern (Marattiales)	Laveine (1969)	Traverse (1988)
Sphenopsids			
Calamospora spp.[c]	*Calamites*	Hartung (1933)	Smith (1962)
	Sphenophyllum	Remy and Remy (1955)	Smith (1962)
Vestispora spp.[c]	*Calamites*	Good (1977)	Traverse (1988)
	Sphenophyllum	Ravn (1983)	Traverse (1988)
Gymnosperms			
Dictyotriletes sp.[b, d]	Pteridosperm	Benson (1904)	Smith (1962)
Florinites spp.[c]	*Cordaites*	Florin (1936, 1938-1940)	Smith (1962)
Unknown affinity			
Latosporites sp.[a]			
Microreticulatisporites spp.[c]			
Triquitrites spp.[c]			

[a]found only at locality BB-29
[b]found only at locality BB-30
[c]found at both localities
[d]of both Fern and Pteridosperm(?) affinity

*for bibliographic information, see Reference Source(s)

Figure 7.1. Paleobotanical affinities of miospore genera recovered by Hyde et al. (1991) from coal seams at localities BB-29 and BB-30 (=Blanche Brook South and North of Hyde et al. 1991, respectively). Information on affinities in part from Calder (1993).

Figure 7.2. Distribution and relative abundances of taxa of Blanche Brook Assemblage within interpreted sublithofacies.

A thick rind of decay- and water-resistant bark supported and protected aerial components of the trees, which may have reached 40 m in height and over 1 m in basal diameter (Wnuk 1985; DiMichele and DeMaris 1987). In comparison, smaller lycopsids similar to the extant *Selaginella* (Thomas 1997) were represented by such forms as *Chaloneria* sp., which consisted of an unbranched stem only ca. 1 to 2 metres tall and ca. 10 cm in diameter (DiMichele et al. 1979; Pigg and Rothwell 1983). Extensive but shallow rhizophores of the *Stigmaria ficoides*-type served to anchor arborescent *Lepidophloios-Lepidodendron-Diaphorodendron* trees to the substrate, while rooting organs of *Sigillaria* sp. had a distinctly different internal morphology (Eggert 1972).

7.2.1.1 *Stigmaria* spp. – Stigmarian rhizophores, which had helically arranged, water-absorbing lateral appendages ("rootlets"), were characterized by large lacunae or air chambers that permitted root growth at or under the water table level. *Stigmaria ficoides* is extremely abundant at Blanche Brook, and the taxon was recorded *in situ* in sediments that accumulated under reducing conditions in the floodplain and clastic swamp sublithofacies (Fig. 7.2). Rhizophores of *S. ficoides* found in a crevasse splay deposit at locality BB-30 presumably are allochthonous debris, while stigmarian organs of unknown affinity were found in the levee/backlevee sublithofacies at locality BB-32.

Stigmaria ficoides is especially prevalent in "simple alluvial paleosols" of the floodplain sublithofacies (Fig. 6.14), which signifies that arborescent lepidodendrid trees were well established on wet (reducing), clastic soils of the floodplain (Fig. 7.3). Autochthonous stigmarian rhizophores within the clastic swamp sublithofacies at locality BB-30 (Fig. 7.2) indicate that lycopsids also comprised part of the biomass in some (but

not all, e.g., BB-14) waterlogged, nutrient-rich clastic swamps (Fig. 7.3) – the abundance of lycopsid taxa represented by miospores from coal seams (Fig. 7.1) indicates several possible parent plants to these root structures. Lycopsids apparently also occupied some slightly better drained levee/backlevee habitats (Fig. 7.3; e.g., BB-32), although it is difficult to ascertain whether the trees were of lepidodendrid or sigillarian origin without knowing the internal morphology of the rhizophores.

7.2.1.2 *Diaphorodendron* sp. – Most species of this arborescent lycopsid (DiMichele 1985) apparently favored exposed to partially submerged, saturated and occasionally flooded peat substrates of coal swamps (DiMichele 1981, 1983; DiMichele and Phillips 1985, 1994). However, evidence of *Diaphorodendron* sp. from clastic swamp or floodplain sediments (Wnuk 1985; Wnuk and Pfefferkorn 1987) indicates that some species could also tolerate living on mineral-enriched substrates. *Diaphorodendron* spp. existed and became increasingly diverse (taxonomically) throughout the Westphalian (DiMichele 1981, 1983; DiMichele et al. 1985; Phillips et al. 1985), but were rare in peat-forming swamps during the "first dry interval" (Duckmantian and Bolsovian; see Fig. 5.4).

Plant organs of "*Lepidodendron*" sp. cf. "*L.*" *bretonense* (=*Diaphorodendron scleroticum*, see DiMichele and Phillips 1994, p. 59) were recovered from the crevasse splay and clastic swamp sublithofacies at Blanche Brook (Fig. 7.2). The tree is represented by decorticated bark and/or small, determinate branches, sporophylls (*Lepidostrobophyllum triangulare*) from disaggregated *Achlamydocarpon varius* cones, *Apiculatisporites* spores (=*Cappospori*tes) from coal seams (Fig. 7.1), and probably by

some of the very abundant, linear leaves referable to cf. *Cyperites bicarinatus*. Abundant sporophylls referred to *Lepidostrobophyllum alatum* from the crevasse splay sublithofacies at locality BB-30 may represent desegregated cones of *A. varius* from another species of arborescent *Diaphorodendron*. However, given that only aerial branches of "*L.*" sp. cf. "*L.*" *bretonense* exist at this locality, it is more plausible that both *L. triangulare* and *L. alatum* sporophylls are derived from the same tree.

It is postulated that "*Lepidodendron*" sp. cf. "*L.*" *bretonense* inhabited the clastic swamps and possibly some floodplains (Fig. 7.3), based on previously interpreted ecological preferences and the presence of abundant autochthonous *Stigmaria ficoides*-type rhizophores within these habitats. The preference of peat substrates for most species of *Diaphorodendron* suggests that "*L.*" sp. cf. "*L.*" *bretonense* may have dominated the clastic swamps at Blanche Brook during those times when peat accumulation exceeded clastic input. However, the reconstruction by Wnuk (1985) of very tall (up to 25 to 35 m), determinate trees of "*Lepidodendron*" *bretonense* growing within clastic substrate swamps (Wnuk 1985) or paleosols of frequently flooded accretionary floodplains (Wnuk and Pfefferkorn 1987) suggests that "*L.*" sp. cf. "*L.*" *bretonense* may also have tolerated growth on the floodplains and in clastic swamps during times of high nutrient input. Oddly, no aerial plant parts of the taxon were recorded from the floodplain lithofacies itself. Given that "*L.*" *bretonense* was an exceedingly tall tree that likely towered above associated vegetation (Wnuk 1985), aerial organs might have been differentially affected by wind and consequently blown from floodplain inhabiting plants by high velocity winds. Some of these aerial components (e.g., leaves, cone sporophylls, determinate

branches) could have been deposited atop accumulating crevasse splays (e.g., BB-30), or even blown into clastic swamps. In contrast, aerial organs found in the clastic swamp sublithofacies may simply represent litter derived from the lycopsid canopy above or peripheral to the swamp, with organ loss resulting from normal physiological processes.

Devolatilized or decoalified adpressions of decorticated lepidodendrid bark, representing either *Diaphorodendron* or true *Lepidodendron*, found within the coarse lithofacies are poorly preserved owing to mechanical abrasion during transport. However, their presence is significant because it hints that at least some lepidodendrid trees were growing proximal to the channel. Scheihing and Pfefferkorn (1984, p. 219) have noted that large trees within modern distributary channels are almost invariably derived from adjacent levees, and are introduced to the fluvial system by bank undercutting during channel migration.

7.2.1.3 *Sigillaria* sp. – Evidence suggests that *Sigillaria* spp. preferred living on slightly better drained, clastic substrates than did *Lepidodendron* spp. and *Diaphorodendron* spp., although the trees were often contemporaneous in habitats such as clastic swamps, floodplains, and levee/backlevees fringing channels (Bartram 1987; Gastaldo 1987; DiMichele et al. 1985; DiMichele and Phillips 1994, see especially fig.7D, p. 55). In addition, sigillarian litter is often found in high diversity plant assemblages (DiMichele and Phillips 1994), indicating growth in habitats where physiological stress was minimal and thus able to support other plant groups. Similarly to lepidodendrids, sigillarians rarely dominated clastic substrate assemblages during the Westphalian (Pfefferkorn and Thomson 1982), although they may have become more

common in the Stephanian. In peat-forming swamps, *Sigillaria* spp. was the dominant arborescent lycopsid genera to survive the major Westphalian/Stephanian extinction (Fig. 5.4), and their subsistence may be attributed to prior adaptations to live in mesic, non-swamp areas of the lowland-wetlands (DiMichele et al. 1985; Phillips et al. 1985).

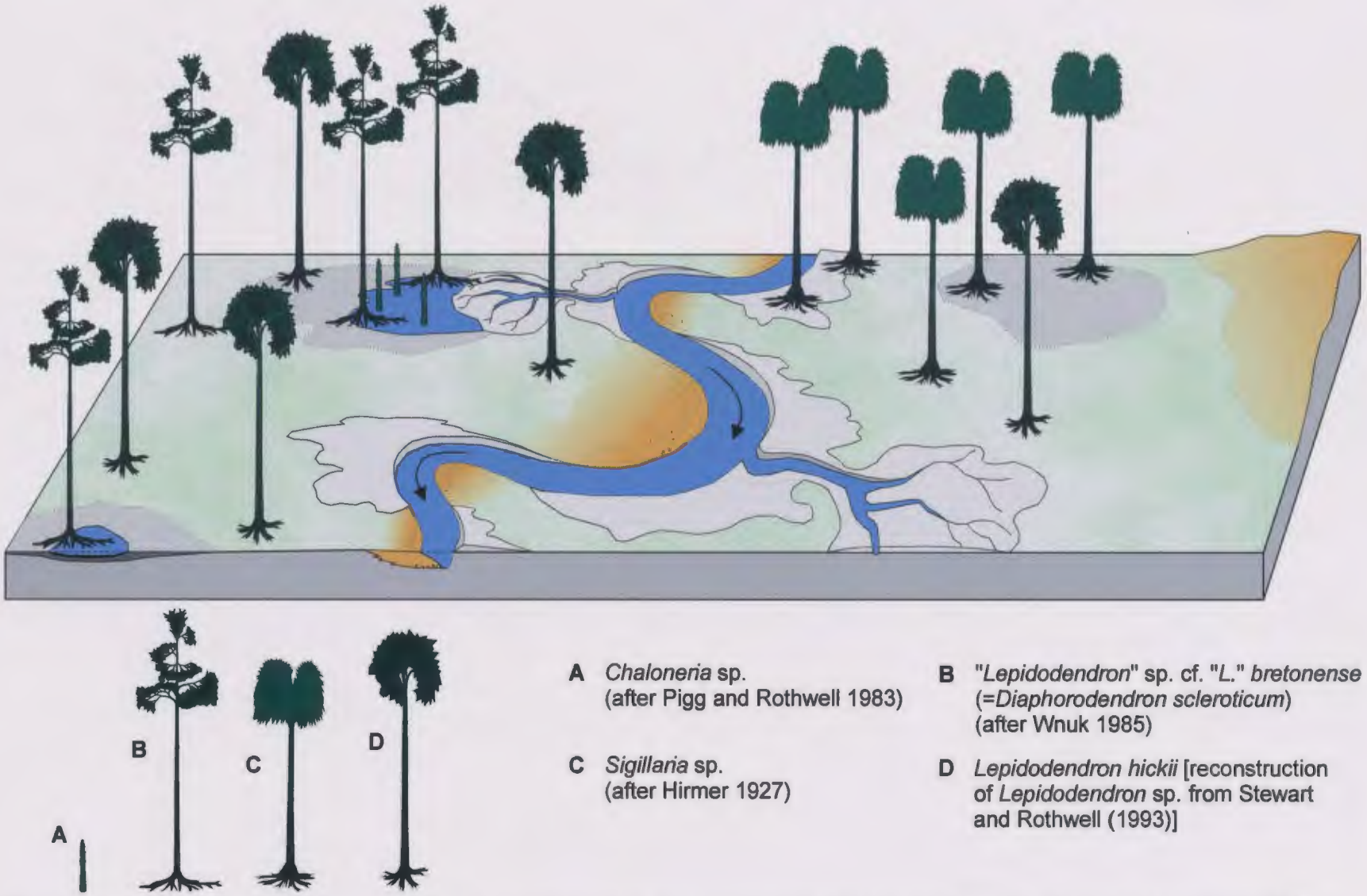
Sigillarian litter is uncommon within the fine (overbank) lithofacies, and is represented only in one subassemblage at locality BB-32 (Fig. 7.2). A single decorticated bark fragment was recovered from floodplain deposits, while muds of the overlying poorly developed clastic swamp sublithofacies contained, together with marattailean tree fern foliage, a single cone sporophyll (*Sigillariostrobus* sp. cf. *S. rhombibracteatus*), moderately abundant, linear leaves (cf. *Cyperites bicarinatus*), and abundant, isolated megaspores referable to *Tuberculatisporites mamillarius*. Additionally, it is possible that a considerable portion of the stigmarian rhizophores recorded from the levee/backlevee and floodplain sublithofacies at BB-32 were anchor systems of sigillarian trees (Fig. 7.3).

Representation of sigillarian litter at only a single locality where diaphorodendrid debris is virtually absent (*L. triangulare* sporophylls are uncommon at the site) poses interesting questions as to the ecological preferences and relationship between these taxa. Significantly, locality BB-32 is the only plant-bearing site along Blanche Brook that records thick accumulation of the levee/backlevee and (to some extent) floodplain sublithofacies (Fig. 6.6), while clastic swamp deposits at the locality are poorly developed and likely were comparatively dry. Thick sediment accumulation and the presence of subterranean rooting organs indicates that these habitats at locality BB-32 were better established, more elevated and thus probably drier than levee/backlevees and

floodplains at other plant-bearing localities along Blanche Brook. Hence, through integration of sedimentological evidence and previous interpretations of ecological preferences, it is postulated that sigillarian lycopsids preferred living on well established, better drained levee/back levees and floodplains where diaphorodendrid and lepidodendrid lycopsids were less common or even absent (Fig. 7.3). The relatively dryer character of substrates in these habitats could explain the lack of aerial litter from plants that grew on them, as increased oxidation and root development would have augmented the potential for chemical and biological degradation of aerial organs. This interpretation is supported by research in modern deltaic environments by Scheihing and Pfefferkorn (1984) who noted that, due to intense oxidation, modern levees are virtually devoid of aerial plant parts derived from levee-inhabiting plants.

Preservation of abundant megaspores and leaves within clastic swamp deposits at locality BB-32 suggests that sigillarian trees may also have been growing in comparatively dry, poorly developed clastic swamps (Fig. 7.3). This supposition is substantiated by the occurrence of miospores attributed to *Sigillaria* spp. (*Crassispora kosankei*) within coal seams at localities BB-29 and BB-30 (Fig. 7.1). Likewise, Bartram (1987) considers the presence of *T. mamillarius* megaspores (among others) indicative of "non-coal swamp" habitats. An alternative hypothesis is that crown litter could have been transported to the clastic swamps via wind from peripheral floodplains, or from even better drained areas fringing the active channel.

Discovery of decorticated sigillarian bark within the channel lag and point bar sublithofacies (Fig. 7.2) provides further evidence that sigillarian lycopsids grew on



A *Chalonería* sp.
(after Pigg and Rothwell 1983)

B "*Lepidodendron*" sp. cf. "*L.*" *bretonense*
(=*Diaphorodendron scleroticum*)
(after Wnuk 1985)

C *Sigillaria* sp.
(after Hirmer 1927)

D *Lepidodendron hickii* [reconstruction of *Lepidodendron* sp. from Stewart and Rothwell (1993)]

Figure 7.3. Hypothetical paleoenvironmental reconstruction with interpreted habitat preferences of lycopsids recovered from Blanche Brook superimposed on meandering stream depositional environment. See Figure 6.18 for labelled distribution of sublithofacies.

levee/backlevees flanking channels, and might have been introduced into the fluvial system by bank undercutting and subsequent collapse.

7.2.1.4 Other lycopsids – Miospore assemblages recovered from coal seams along Blanche Brook indicate that several lycopsid genera (Fig. 7.1), which are not represented by adpressed flora, were living within or peripheral to the clastic swamps. Lycopsids of comparatively short stature are represented by *Chaloneria* sp. and *Sellaginellites* sp. According to DiMichele and Phillips (1994), the former genus occupied high nutrient, more open portions of peat-forming swamps (Fig. 7.3), while *Sellaginellites* sp. grew as understory elements beneath lycopsid forests or in open moor communities of coal swamps (Thomas 1997).

Although the parent plant of *Lycospora noctuina* spores recovered from coal seams is equivocal (Fig. 7.1), the presence of *Lycospora pusilla* spores indicates that *Lepidodendron hickii* (Willard 1989a) was part of the flora at Blanche Brook. *L. hickii* was an arborescent form that favored growth on clastic substrates of floodplains and clastic swamps (DiMichele 1983; DiMichele et al. 1985; Willard 1989b; DiMichele and Phillips 1994), possibly within tree fern and pteridosperm-dominated assemblages (DiMichele 1983). Accordingly, it is plausible that this taxon accounts for many of the autochthonous stigmarian rhizophores present within the floodplain sublithofacies at Blanche Brook. Additionally, *L. hickii* probably overlapped with "*L.*" sp. cf. "*L.*" *bretonense* in the clastic swamps, particularly when clastic accumulation hindered peat formation.

7.2.2 Sphenopsids

Late Carboniferous lowland-wetlands vegetation included two major evolutionary lineages of sphenopsids, *Calamites* spp. and *Sphenophyllum* spp., both of which were characterized by rhizomatous, vegetative propagation. Calamiteans were jointed, somewhat woody, arborescent trees (up to 45 cm wide at base and metres tall) or subtrees with foliage that comprised small whorls of leaflets known as *Annularia* sp. or *Asterophyllites* sp. (Good 1971, 1975, 1976; Barthel 1980). Sphenophylls were characterized by delicate verticils of heterophyllous leaflets that radiated from nodes along thin, woody stems. Sphenophylls growing on clastic substrates have been interpreted as ascending, climbing, ground-cover plants that formed dense, highly branching thickets (Batenburg 1977, 1981), while coal swamp species apparently comprised aerial branching shoots that arose from prostrate, rooting main axes (Batenburg 1982).

7.2.2.1 *Calamites* sp. – Some arborescent calamiteans occupied subaerially exposed and/or nutrient-rich portions of some coal swamps (DiMichele et al. 1985; DiMichele and Phillips 1994). However, these hydrophytic plants seemingly preferred living in loosely consolidated, unstable, wet (or even submerged) sediment more suited to its clonal growth habit, such as shifting substrates found in point bars, levee/backlevees, frequently-flooded floodplains, and swamp margins (Scott 1977, 1978, 1979; Gastaldo 1987; DiMichele et al. 1985, 1992). According to Pfefferkorn and Thomson (1982), calamitean stems and foliage were co-dominants (with pteridosperms) in the majority of

late Namurian through middle Westphalian D adpression plant assemblages recovered from clastic substrate habitats.

By far the most abundant and best preserved (although quite fragmented) calamitean plant remains were recovered from crevasse splay deposits at locality BB-30 (Fig. 7.2). These organs include axes, tiny rootlets (*Pinnularia capillacea*), fructifications (*Paracalamostachys* sp.), and (frequently articulated) foliage referable to *Annularia sphenophylloides*, *A. stellata* and *Asterophyllites equisetiformis*. In addition, a large rooting structure comparable to *Myriophyllites gracilis* was the only identifiable plant organ recovered from a crevasse splay at BB-29. Unfortunately, plant organs within crevasse splay deposits may have been incorporated into the sublithofacies from various habitats (Gastaldo et al. 1987), which confounds interpretations of provenance.

Devolatilized and decarbonized adpressions and petrifactions of calamitean axes are rather common as debris within the channel lag and point bar sublithofacies along Blanche Brook (Fig. 7.2). Although these stems have been transported (Fig. 6.9) and somewhat mechanically abraded, they are thought to have comprised part of the riparian flora growing on poorly developed levees or even on laterally accreting point bars (Fig. 7.4; see also Scott 1978, 1979). That calamiteans grew in these channel margin habitats is supported by the recovery of thin axial fragments and delicate, typically articulated, branches of foliage identified as cf. *Asterophyllites* sp. from what are interpreted as levee/backlevee deposits at locality BB-19. Despite articulation of the branches, the foliage likely are not autochthonous, but rather was somewhat fragmented during a short episode of transport before deposition and burial. In comparison, Gastaldo (1987)

recorded an *in situ* macrofloral assemblage from backlevee deposits within which lateral branches and *Asterophyllites* sp. foliage still remained attached to calamitean stems. By induction, it is interpreted that calamitean litter at locality BB-19 was derived from riparian vegetation growing on point bars and/or levees, and that the plant organs probably were transported to backlevees when minor flood events overtopped channel banks.

Vertical, carbonate-infilled fractures with circular outlines observed in red, bioturbated mudstones of the floodplain sublithofacies at locality BB-5 (Fig. 6.16) are interpreted as replaced plant stems, possibly of *Calamites* sp. (see p. 222). In addition, a single axial fragment (*Calamites* sp. B) was recovered from floodplain deposits at locality BB-25, although the stem may have been transported to the site. It is possible then that calamiteans may also have grown as an understory plant on floodplains (Fig. 7.4), as has been interpreted at other sites by Scott (1978, 1979) and Wnuk (1985), although evidence from Blanche Brook is only speculative at best.

It is significant to note that absolutely no adpressed calamitean litter was found in any clastic swamp deposits at Blanche Brook (Fig. 7.2). However, recovery of miospores of calamitean affinity in coal seams (Fig. 7.1) indicates that the plants may in fact have inhabited parts of this depositional setting (Fig. 7.4), although wind or water may have transported some miospores to the clastic swamps.

7.2.2.2 *Sphenophyllum* sp. – A crevasse splay deposit at BB-30 contains a significant number of isolated whorls and articulated branches of *Sphenophyllum emarginatum*, while leaflet fragments of *S.* sp. cf. *S. zwickaviense* are quite rare. Rare

fragments of *S. emarginatum* have also been recovered in association with pteridosperm foliage from silty layers within the clastic swamp sublithofacies at locality BB-14. Unfortunately, the potentially allochthonous nature of fossils from both sublithofacies (see discussion of clastic swamp flora at locality BB-14 on p. 251) precludes inferences of the provenance or paleoecology of parent plants.

Both *S. emarginatum* and *S. zwickaviense* evidently inhabited clastic substrates and probably were xerophytes (Storch 1966) or more likely mesophytes (Batenburg 1981) that lived on unsubmerged (except during floods), well drained soils of floodplains or channel margins (Scott 1979; DiMichele et al. 1992). The presence of sphenophyll thickets in these habitats at Blanche Brook can neither be confirmed nor denied. The recovery of miospores attributed to sphenophylls from coal seams at localities BB-29 and BB-30 (Fig. 7.1) suggests that some plants may have been growing peripheral to or even within the clastic swamps at Blanche Brook (Fig. 7.4).

7.2.3 Tree Ferns

Axes of herbaceous and homosporous marattialean tree ferns (dominated by *Psaronius* sp.) were rather "cheaply" constructed and comprised a thin, somewhat fleshy stem mantled by a thick layer of aerenchymatous, adventitious, supporting roots (Morgan 1959; Stidd 1971; Pfefferkorn 1976; Ehret and Phillips 1977; Mickle 1984; Millay 1997). Stems attained heights of ca. 10 m and widths of ca. 1 m (Taylor and Taylor 1993), and were topped by an umbrella-like crown of pinnate fronds of *Pecopteris*-type foliage. Fronds attained several metres in length (Stewart and Rothwell 1993) and contained taxonomically distinct sporangia on the abaxial pinnule surfaces (Millay 1979).

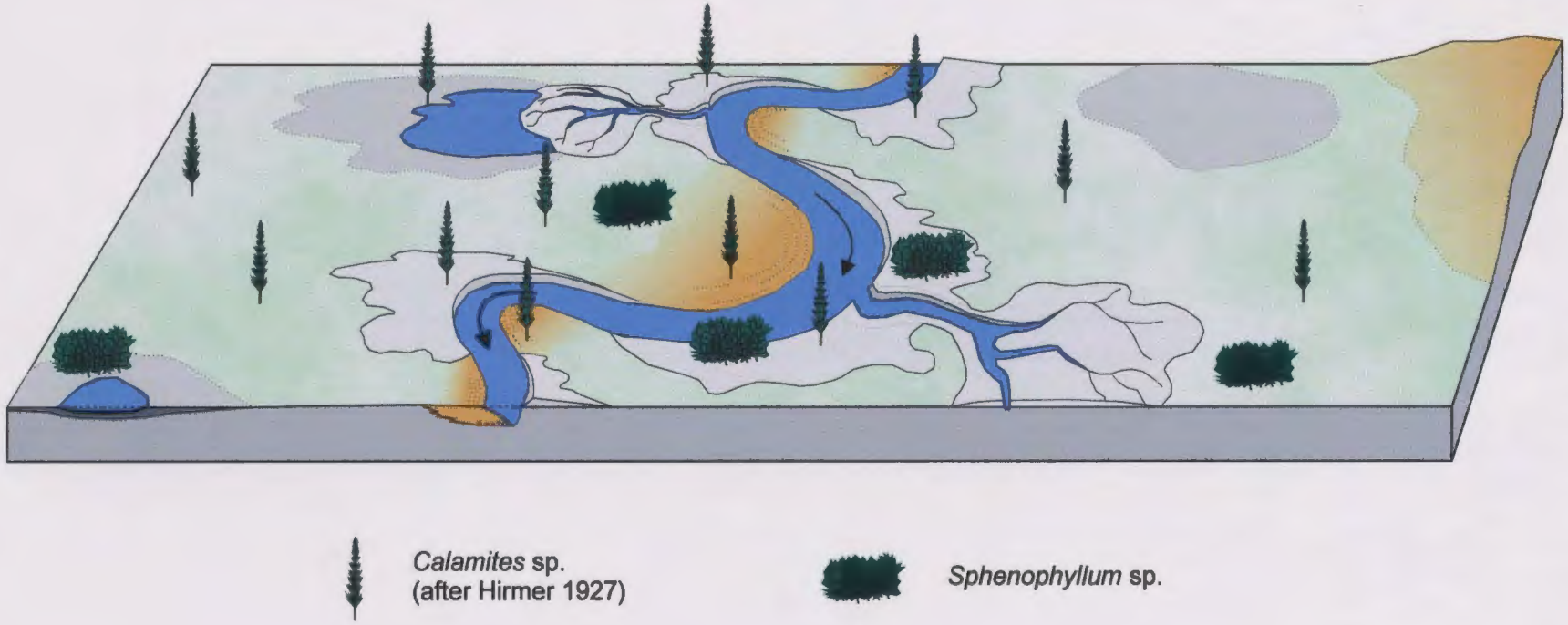


Figure 7.4. Hypothetical paleoenvironmental reconstruction with interpreted habitat preferences of sphenopsids recovered from Blanche Brook superimposed on meandering stream depositional environment. See Figure 6.18 for labelled distribution of sublithofacies.

Aerenchymatous roots supposedly permitted marattialean tree ferns to survive in various clastic and peat substrate habitats that may have been strongly influenced by fluctuating water tables or even temporary submergence during flood events (DiMichele and Phillips 1994). These authors have shown tree ferns growing in nutrient-rich and aerially exposed parts of coal or clastic swamps, and also on well drained levees (fig. 7B, C, p. 54-55; fig. 11B, p. 66). Scott (1978, 1979) suggested that ferns may have been co-dominant with pteridosperms on floodplains.

Palynological and macrofloral (adpression) evidence indicates that marattialean tree ferns were centered in mesic lowland settings where they had low but increasing diversity during Langsettian through middle Westphalian D time (Figs. 5.4; Phillips 1979; Pfefferkorn and Thomson 1982; DiMichele et al. 1985). However, above the middle Westphalian D, *Pecopteris* spp. and "fern" species of *Sphenopteris* spp. dominated adpression assemblages (Pfefferkorn and Thomson 1982). In coal swamps, a shift from lycopsid to marattialean tree fern dominance is observed somewhat later at the onset of the "second drier interval" (Westphalian/Stephanian boundary; Fig. 5.4) (DiMichele et al.1985; Phillips et al. 1985).

Pecopterids are a subdominant component of the whole BBA, comprising at least five species, while sphenopterids are very rare. The crevasse splay deposit at locality BB-30 contains an abundance of foliar fragments identified as *Lobatopteris* sp. A, with less common *Pecopteris plumosa* and *Pecopteris* sp. A (Fig. 7.2), among others. Although part of an allochthonous assemblage, the relatively large size (up to 34.5 cm long) and comparatively less fragmented, articulated nature of these frond fragments,

which are rather delicate organs, suggests they were not transported far before burial. It is possible then that some pecopterids were growing peripheral to or even within the clastic swamp (Fig. 7.5), and could have been incorporated into the erosively based crevasse splay as it passed over and essentially infilled the swamp/pond. The presence of *Lobatopteris* sp. A and *Pecopteris* sp. A together with sigillarian litter within the clastic swamp sublithofacies at locality BB-32 (Fig. 7.2, Fig. 7.5) supports interpretations of a clastic swamp habitat for several pecopterid species. This hypothesis is further strengthened by the occurrence of a number of miospore genera in coal seams that belong to foliage of various marattialean and filicalian tree ferns (Fig. 7.1).

An alternative hypothesis is that some tree ferns grew on levees and floodplains as part of the subcanopy with medullosan pteridosperms and possibly calamitean trees, as has been previously reconstructed by Scott (1978, 1979). Accordingly, it is possible that tree fern foliage was incorporated into crevasse splays when they breached the well vegetated levees (e.g., Scheihing and Pfefferkorn 1984; Gastaldo et al. 1987). The essential absence of tree fern debris from the levee and floodplain sublithofacies (only the floodplain sublithofacies at locality BB-25 yielded very rare and very fragmentary pecopterid and sphenopterid(?) litter) could be explained by preferential oxidation of aerial components in these better drained habitats. It must also be considered that crown frond fragments and miospores were traumatically removed by violent winds from floodplain and levee inhabiting tree ferns and transported a short distance either to clastic swamps or the crevasse splay surface.

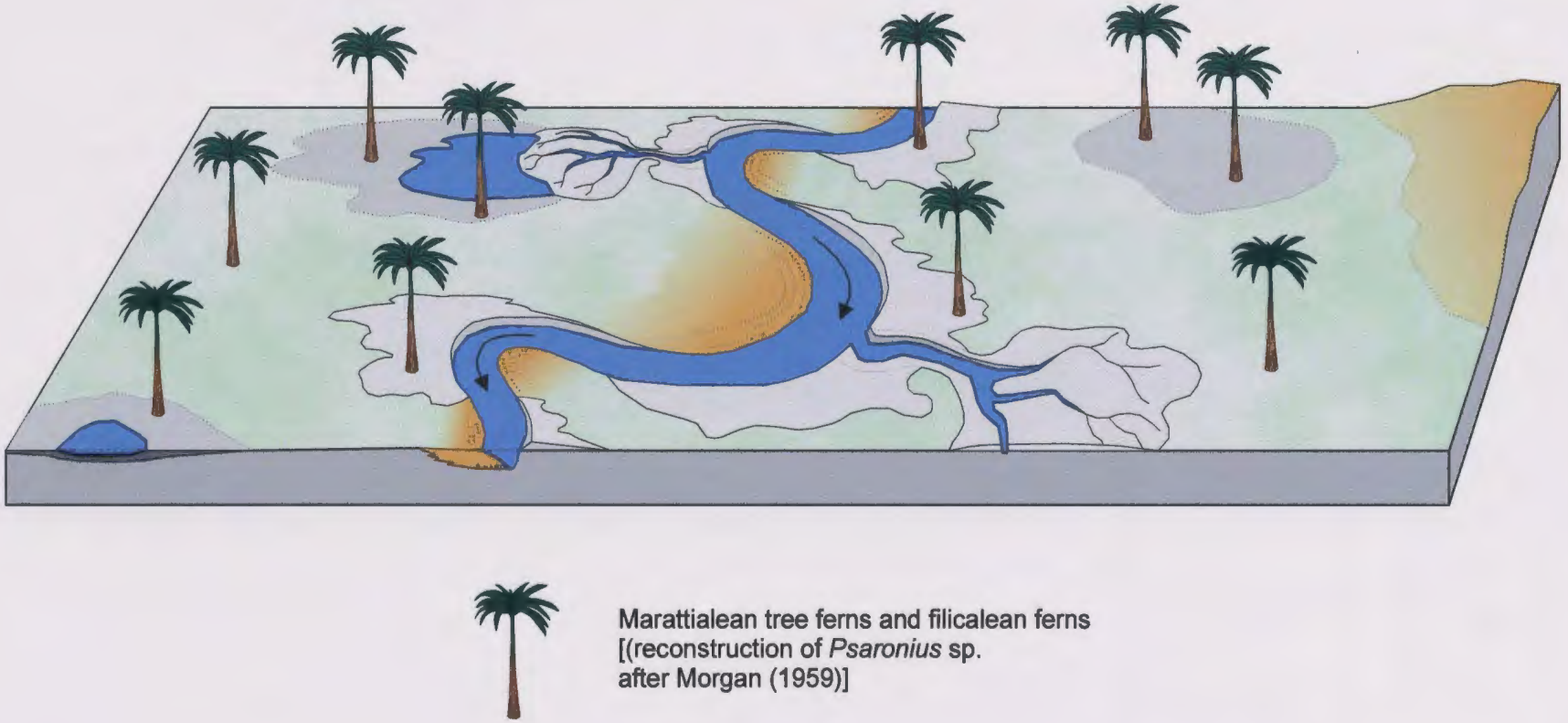


Figure 7.5. Hypothetical paleoenvironmental reconstruction with interpreted habitat preferences of marattialean tree ferns and filicalean ferns recovered from Blanche Brook superimposed on meandering stream depositional environment. Note that the *Psaronius* sp. (Marattiales) reconstruction is meant to represents both marattialean and filicalean ferns (Filicales). See Figure 6.18 for labelled distribution of sublithofacies.

Importantly, the growth of marattialean and/or filicalean tree ferns in or peripheral to clastic swamps implies that the swamp substrate upon which they grew was wet but not submerged, as tree ferns require an exposed surface for completion of their free-sporing life cycle (DiMichele and Phillips 1994). It is also noteworthy that, although filicalean ferns are an uncommon component of the entire BBA (with the exception of *Pecopteris plumosa*), paleobotanical affinities of miospores from coal seams indicates that a considerable number of other filicalean ferns inhabited some clastic swamps and/or peripheral habitats.

7.2.4 Pteridosperms

Seed-producing pteridosperms of tree habit (anatomically preserved stems referred to *Medullosa* sp. or *Sutcliffia* sp.) had monoaxial stems comprising bundles of vascular tissue embedded in a dense cortical groundmass (Delevoryas 1955; Stewart and Delevoryas 1956). Two tree morphologies existed – some were free standing (up to 5 m in height), while others were lax and supported by neighboring plants (up to 10 m) (Pfefferkorn et al. 1984; Wnuk and Pfefferkorn 1984). Fronds arising from near the top of axes often were massive (several metres in length, see Laveine 1986), rather robust, bore large seeds and pollen organs, and constituted pinnate laminae. Adpressed foliage is referred to, among others, *Linopteris* sp. (belonging to *Sutcliffia* sp. stems), or *Neuropteris* sp. *sensu lato* and *Alethopteris* sp. (belonging to *Medullosa* sp.stems) (Taylor and Taylor 1993). Upon death, fronds may have folded back against the axis to form a "skirt" of decaying foliage that supported the stem (Pfefferkorn et al. 1984).

7.2.4.1 Medullosan pteridosperms – Medullosan trees growing in clastic substrate habitats apparently encompassed a wide range of ecological strategies, with different preferences for soil moisture and nutrient content and sun and wind intensities demarcated along generic or even specific lines (e.g., Reihman and Schabilion 1978; Phillips 1981; Mickle and Rothwell 1982; Wnuk and Pfefferkorn 1984; Schabilion and Reihman 1985; Cleal and Zodrow 1989; Zodrow and Cleal 1993; DiMichele and Phillips 1994). The trees seemingly had similar ecological preferences to contemporaneous tree ferns, and favored moist but unsubmerged, clastic substrates that were comparatively nutrient-rich and well drained (Phillips 1981). Suitable habitats that have previously been inferred include levee/backlevees, floodplains, clastic swamps and nutrient enriched, subaerially exposed parts within or peripheral to peat-forming swamps (e.g., Scott 1977, 1978, 1979; Phillips 1981; Wnuk and Pfefferkorn 1984, 1987; DiMichele et al. 1985; Gastaldo 1985, 1987; Wnuk 1985; Zodrow and Cleal 1988; DiMichele and Phillips 1994; Phillips and DiMichele 1998).

That medullosan seed ferns likely diversified outside peat-forming environments is evident from studies of Pfefferkorn and Thomson (1982) which show pteridosperm (*Neuropteris* sp. *sensu lato* and *Alethopteris* sp.) dominance in nearly all adpression assemblages recovered from late Namurian through middle Westphalian D strata. Peat substrate-inhabiting medullosans apparently were very rare from the Langsettian through Bolsovian, with expansion and diversification occurring throughout the Westphalian D "wet interval" before co-dominance with tree ferns during the Stephanian (Fig. 5.4; Phillips 1981; DiMichele et al. 1985; Phillips et al. 1985).

Floodplain (BB-25) and crevasse splay deposits (BB-30) both contain a considerable quantity of isolated pinnules and pinnae fragments referable to *Neuropteris semireticulata*, while other medullosan foliage form-genera are conspicuously rare or even absent. The increasingly flexuous venation pattern that typifies pinnules of *N. semireticulata* and its rather closely related evolutionary descendant *Reticulopteris muensteri* (see p. 113 for discussion) have been correlated by Zodrow and Cleal (1993) with the increasingly drier climatic conditions that transpired in Duckmantian through Bolsovian time ("first dry interval" in Fig. 5.4). These paleoecological data, in combination with sedimentological evidence, suggest that *N. semireticulata* preferred to inhabit reasonably well drained, comparatively dry substrates on levee/backlevee complexes and possibly proximal floodplains (Fig. 7.6). It is important to note, however, that evidence garnered from anatomical studies of *R. muensteri* suggests that this species, and by analogy its ancestor *N. semireticulata*, still lived under moist, high humidity conditions (Reihman and Schabilion 1978), perhaps growing as a shaded understory beneath large cordaitean trees (Schabilion and Reihman 1985).

Discrete, greyish green silt horizons interspersed within carbonaceous shales of the clastic swamp sublithofacies at locality BB-14 invariably contain highly fragmented neuropteroid foliage (isolated pinnules or less frequently pinnae fragments) referable to *Laveineopteris rarinervis* and cf. *Laveineopteris tenuifolia*. These comparatively coarser, fossiliferous bands are thought to represent deposition resulting from periodic flood events (concurrent with violent winds?) that sampled vegetation from several wetland habitats.

Investigations of anatomically preserved *L. rarinervis* foliage (Reihman and Schabilion 1978; Oestry-Stidd 1979) indicates that the taxon preferred high humidity, moist habitats, perhaps living under shaded conditions (Schabilion and Reihman 1985), or occupying topographically lower areas of floodplains where the water table was at or near the soil surface (Wnuk and Pfefferkorn 1984). Conversely, Barthel (1962) considered that *L. tenuifolia* was adapted to growing under physiologically stressed (i.e., drier) conditions. Although morphological adaptations to physiological drought may result from living in a truly edaphically-drier setting, they may also be adapted by plants growing in nitrogen-deficient habitats (e.g., in acidic, peat-forming environments), under intense sunlight (Shields 1950; Mickle and Rothwell 1982), or in open canopies exposed to intense wind (Cleal and Zodrow 1989). As there is no evidence for nitrogen-deficient, extensive, peat-forming habitats at Blanche Brook, it is instead postulated that cf. *L. tenuifolia* lived on edaphically-drier clastic substrates (under comparatively more intense sunlight? and/or wind?), perhaps on the floodplain or even levees (Fig. 7.6). Meanwhile, *L. rarinervis* might have lived peripheral to the clastic swamp on wetter portions of the distal floodplains under slightly more humid, moist (and more shaded?) conditions (Fig. 7.6), although there almost certainly would have been an ecological coalescence between these habitats and their flora. The interpretation that cf. *L. tenuifolia* lived further from the clastic swamp (and thus was transported further) is supported by the fact that its litter at locality BB-14 invariably consists of isolated pinnules, while *L. rarinervis* debris from the same siltstone horizons is generally preserved as less degraded pinnae fragments.

With the exception of *N. semireticulata*, and perhaps cf. *L. tenuifolia*, there is otherwise a scarcity within the BBA of medullosan pteridosperms that evidently lived under physiologically drier conditions, such as *Macroneuropteris scheuchzeri* and some alethopterids. For example, *M. scheuchzeri* is represented only by a single pinnule adpression from clastic swamp deposits at locality BB-14 (Fig. 7.2), while a single alethopterid(?) pinnule fragment was recovered from the crevasse splay sublithofacies at locality BB-30. Wnuk and Pfefferkorn (1984) inferred that both taxa lived on (micro)topographically higher, better drained portions of floodplains or swamps(?), while Schabilion and Reihman (1985) considered the foliage to represent "sun leaves" that apparently lived under intense sunlight. Alternatively, Cleal and Zodrow (1989) asserted that xeromorphic features of *M. scheuchzeri* reflect adaptations to living under more exposed and consequently windier conditions. Regardless of the reason(s) for development of xeromorphic characteristics, it is worth considering the possibility that these taxa are absent from Blanche Brook because their ecological niche was instead occupied by *N. semireticulata* (Fig. 7.6).

It is significant that no medullosan pteridosperm foliage (except a single *Cyclopteris* sp. pinnule of equivocal affinity) was recovered from clastic swamp deposits at locality BB-32. It is important to recall that this is the same site where the associated levee/backlevee, floodplain and clastic swamp sublithofacies were comparatively well developed and likely better drained, and may have supported stands of arborescent sigillarians (see p. 237-238). Hence, it is possible that pteridosperms interpreted to have preference for well drained substrates, such as *N. semireticulata*, *M. scheuchzeri* and

some alethopterids, may have competed with and only occasionally coexisted with arborescent *Sigillaria* sp. (Fig. 7.6), a taxon that preferred living in the same ecological niche. Alternatively, edaphic conditions at the site may have been too dry to support pteridosperms, indicating that sigillarians could withstand conditions of considerable water stress.

Evidence of fairly strict, physiological and ecological preferences of medullosan pteridosperms recovered from strata at Blanche Brook substantiates previous assertions (e.g., Reihman and Schabilion 1978; Phillips 1981; Wnuk and Pfefferkorn 1984; Schabilion and Reihman 1985) that ecological partitioning was the rule rather than exception between genera and species within the pteridosperms. It is also plausible that there was competition for particular niches between pteridosperms and members of the other major Late Carboniferous plant groups.

7.2.4.2 *Sutcliffia* sp. – Pinnules assigned to *Linopteris* sp. are characterized by finely anastomosing venation and represent the paripinnate and caducous foliage of the pteridosperm *Sutcliffia* sp. (Stidd et al. 1975). Linopterids are quite rare within the BBA, represented only by isolated pinnules of *Linopteris neuropteroides* within the levee/backlevee sublithofacies at locality BB-19 (Fig. 7.2). Sphenopsid litter associated with the pinnules was previously interpreted (p. 242-243) as having been derived from flora growing on point bars or channel levees. It is postulated in accordance that small *Sutcliffia* sp. trees also inhabited channel fringing levees, with the caducous pinnules which characterize the group transported to the back levee either by wind or flood events.

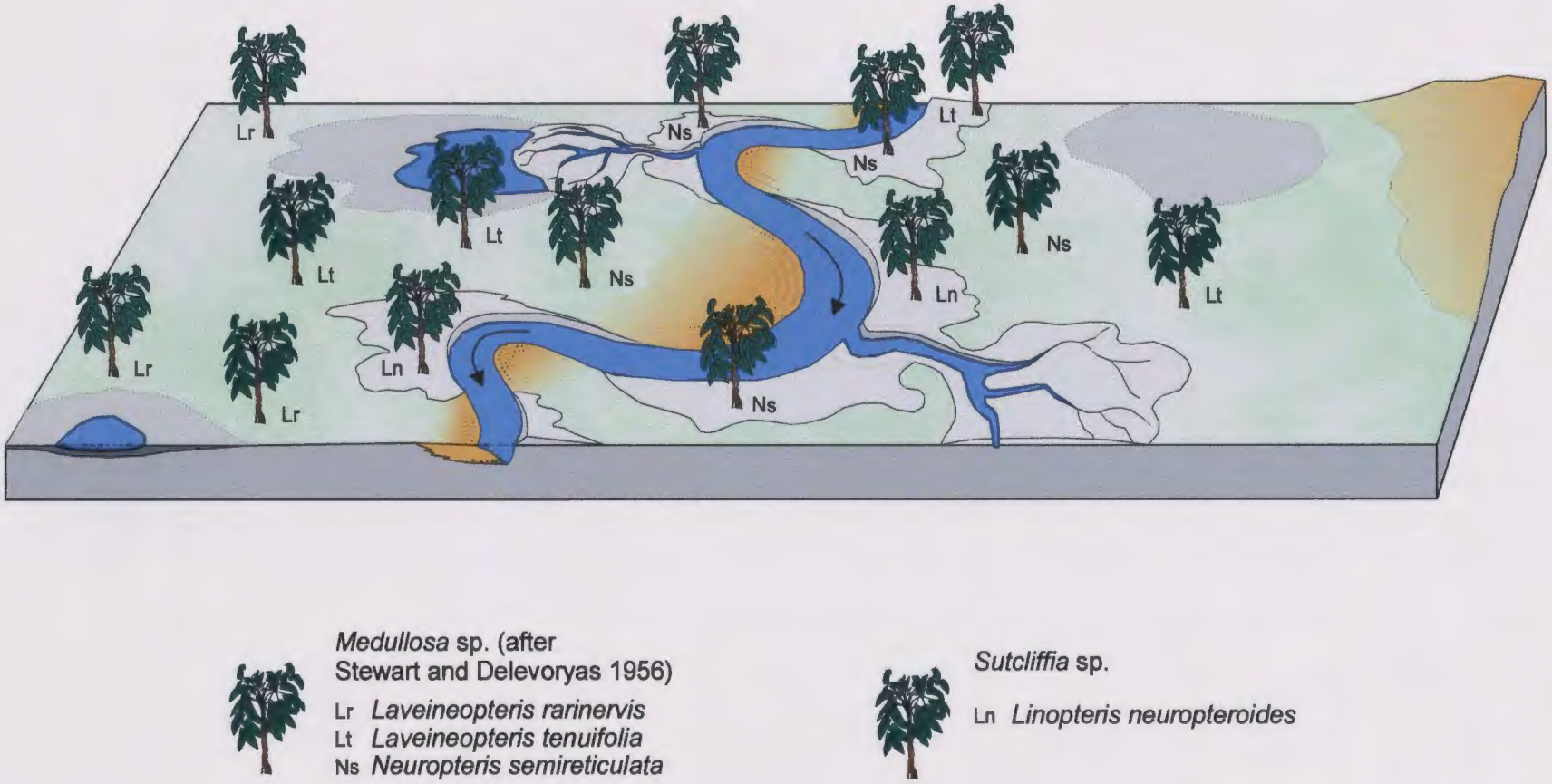


Figure 7.6. Hypothetical paleoenvironmental reconstruction with interpreted habitat preferences of medullosan and *Sutcliffia* sp. pteridosperms recovered from Blanche Brook superimposed on meandering stream depositional environment. See Figure 6.18 for labelled distribution of sublithofacies.

7.2.5 Cordaiteans

Cordaiteans constitute a diverse group of comparatively slow growing and long lived, seed-producing plants that were structurally similar to modern conifers and had extremely variable growth habits. In general, the group was characterized by pycnoxylic (dense) wood, strap-shaped, coriaceous leaves with thick cuticle and abundant sclerenchyma, axillary branching, and wind dispersed, platyspermic seeds (DiMichele et al. 1986, 1992; Rothwell 1988; DiMichele and Phillips 1994). Three main cordaitean stems genera have been established – *Cordaixylon* sp., *Mesoxylon* sp. and *Pennsylvanioxylon* sp. – although considerable contention presently exists as to which anatomical stem features are taxonomically robust (e.g., Rothwell and Warner 1984; Costanza 1985; Trivett and Rothwell 1985, 1991; Trivett 1992). As such, rather than discuss the paleoecology and temporal distribution of each taxon, "extrabasinal and upland" inhabitors will be discussed separately from clastic or peat swamp inhabitors.

7.2.5.1 Swamp inhabitors – There is limited paleoecological data pertaining to cordaiteans living in clastic swamps, although some inferences likely can be made by comparison with those which occupied peat-forming swamps. These cordaiteans were both biologically and ecologically variable, and included mangrove-like forms up to 5 m tall with adventitious, aerenchymatous, stilt-like roots (Cridland 1964; Raymond and Phillips 1983; Costanza 1985; Raymond 1988), and small, thicket-forming, understory shrubs (Rothwell and Warner 1984; Costanza 1985). As a group, the swamp-dwelling forms apparently encompassed a broad spectrum of ecological tolerances, including growing within and peripheral to swamps on substrates that either were subaerially

exposed, waterlogged, or periodically or permanently inundated with fresh, brackish or even saline waters (Cridland 1964; Wartmann 1969; Eggert and Phillips 1982; Raymond and Phillips 1983; Costanza 1985; Trivett and Rothwell 1985; Raymond 1988; Calder 1993). Cordaiteans were especially important components of peat-forming swamps during the "first dry interval" (Duckmantian/Bolsovian), and during the first part of the increasingly wetter interval that characterized the Westphalian D (Fig. 5.4) (DiMichele et al. 1985; Phillips et al. 1985).

On the whole, cordaitean leaves are the most abundant floral element of the BBA, and constitute the dominant or a subdominant component of plant debris from clastic swamp deposits at locality BB-14, and from the clastic swamp and crevasse splay sublithofacies at locality BB-30 (Fig. 7.2). *Cordaites* sp. cf. *C. principalis* adpressions are extremely abundant in dark grey, very carbonaceous, pyritic and typically parallel laminated shales that comprise the majority of the clastic swamp sublithofacies at localities BB-14 and BB-30. [*Cordaites* sp. cf. *C. borassifolia* leaves are only rare in clastic swamp deposits at locality BB-30, and may in fact represent differentially preserved examples of *C.* sp. *C. principalis* (see p. 124 for discussion)]. Sedimentological evidence (e.g., high organic content, parallel laminae, pyrite nodules) suggests that these leaves accumulated in nutrient- and oxygen-deficient, standing water within the clastic swamps and succeeding anoxic ponds. In contrast to pteridosperm foliage recovered from silt horizons in the clastic swamp sublithofacies at locality BB-14, which are interpreted as deposits of short lived storm events, it is reasonable to induce that cordaitean leaves were steadily being added to the clastic swamp under "normal" or

non-storm conditions. This suggests that the parent plant of *C.* sp. cf. *C. principalis* (and of *C.* sp. cf. *borassifolia*, if different) was growing within and/or directly surrounding some of the clastic swamps and succeeding ponds (Fig. 7.7). Leaves might have been lost either through physiological or traumatic processes, and deposited very close to their site of growth [hypoautochthonous or parachthonous litter *sensu* Gastaldo (1988) and Bateman (1991), respectively]. This interpretation is strengthened by the reconstruction by Costanza (1985) of *C. principalis* leaves attached to small (up to 5 m), mangrove-like trees referred to *Pennsylvanioxylon birame* [=*Cordaixylon birame* of Trivett (1992)], a form which inhabited frequently flooded swamps containing anoxic and acidic but fresh water (Eggert and Phillips 1982; Costanza 1985). [Note that Trivett and Rothwell (1991) and Trivett (1992) demonstrated that *C. principalis* leaves were instead borne by the plant *Cordaixylon iowensis*, not *C. birame*, but gave no paleoecological interpretation of the whole plant]. Recovery by Hyde et al. (1991) from coal seams (Fig. 7.1) of *Florinites* spp. pollen, which are attributed to mangrove-like or scrambling, shrub-like, swamp-inhabiting *Pennsylvanioxylon* spp. (Trivett 1992; DiMichele and Phillips 1994), lends further considerable support to the interpretation that clastic swamps, or swamp peripheries, might have been inhabited by cordaitean plants (probably *Pennsylvanioxylon* spp?; Fig. 7.7). Furthermore, DiMichele and Phillips (1994) noted the frequent association of subcanopy, woody, scrambling cordaiteans with arborescent swamp-dwelling *Diaphorodendron* lycopsids at other fossil localities, which provides additional evidence that cordaiteans formed a subcanopy beneath "*L.*" sp. cf. "*L.*" *bretonense* in the clastic swamps at Blanche Brook.

It is worth mentioning Schabilion and Reihman's (1985) conclusions that xeromorphic features observed in many cordaitean leaves (e.g., thick cuticles, extensive aerenchymatous mesophyll, papillate lower epidermis) represent adaptations to living under intense sunlight ("sun leaves"). It is possible though, at least for those cordaiteans at Blanche Brook that are interpreted as clastic swamp-dwelling plants, that such adaptations resulted from physiological drought, and reflect growth under nitrogen- and oxygen-deficient conditions.

Interestingly, poorly preserved but moderately abundant fragments of *C.* sp. cf. *C. principalis* foliage were also recorded in the floodplain sublithofacies at locality BB-25. This suggests that although the parent plant of *C.* sp. cf. *C. principalis* (perhaps *C. iowensis* or *C. birame*) may have been centered in clastic swamps, it may also have tolerated living on slightly better drained parts of the distal floodplain.

The crevasse splay sublithofacies at locality BB-30 contains a profusion of cordaitean foliage (Fig. 7.2) referable to *C.* sp. cf. *C. principalis* and *C.* sp. cf. *C. borassifolia*, particularly in the lowest cms of the unit, with fructification fragments, platyspermic seeds and *Cordaites* sp. A foliage being rare. Similarly to much of the tree fern foliage, this cordaitean debris is interpreted to have been incorporated into the crevasse splay as it passed over the clastic swamp and entrained litter or living organs of the parent plants. Moreover, some of the litter, particularly seeds and leaves, may have been blown onto the crevasse splay surface.

7.2.5.2 Inhabitors of "extrabasinal and upland" habitats – Large (up to 10s of metres tall), many branched, forest-forming trees apparently grew on well drained or

even dry clastic substrates of levee/backlevees, stable parts of floodplains, and even coetaneously with conifers in "upland" areas (Grand'Eury 1877; Chaloner 1958; Scott 1979; Mapes and Gastaldo 1986; Rothwell 1988). Although cordaitean trees likely lived in these clastic substrate habitats from earliest Late Carboniferous (Leary 1981) through Stephanian and early Permian time (Lyons and Darrah 1989), they dominate very few Late Carboniferous adpression assemblages (Pfefferkorn and Thomson 1982).

One of the most distinctive features of the channel lag and point bar sublithofacies at Blanche Brook is the presence of abundant, very large, volatilized tree petrifactions referable to *Dadoxylon* sp. (petrifactions up to 4.8 m long and with basal diameters near 2.0 m). These trees are interpreted to represent the remains of large forest-forming cordaitean trees (*Eu-Cordaites sensu* Grand'Eury 1877). These permineralized trees almost certainly are allochthonous, based on their current aligned, almost invariably prostrate disposition in trough cross-stratified channel sandstones and gravels, although it is not possible to ascertain the distance of transport. It is postulated that many of the trees grew on well drained levee/backlevees flanking the channel where they formed a very high, shading canopy above contemporaneous vegetation (Fig. 7.7). Trees would have been added to the fluvial system by lateral stream migration and consequent bank undercutting and collapse, and logs may have floated some distance before becoming waterlogged and sinking to become buried in the channel lag and point bar deposits (Scheihing and Pfefferkorn 1984). It must also be considered that tall *Dadoxylon* sp. (*Eu-Cordaites*) trees might have inhabited forests on dry clastic soils of elevated slopes of the extrabasinal uplands comprising the catchment area surrounding the narrow floodplain

(Fig. 7.7). It is not clear how such large trees would be brought to the river system, although transport may have occurred during exceptional mass wasting events affecting the otherwise poorly vegetated(?) slopes.

Cordaites sp. B leaves that show evidence of mechanical degradation (i.e., longitudinal splitting) due to transport are moderately common elements of point bar sandstones at locality BB-34 and the floodplain sublithofacies at locality BB-25. The leaves are considerably more broad and have a distinctly different venation pattern than *C.* sp. cf. *C. principalis*-type foliage borne on comparatively shorter trees that evidently lived within or surrounding clastic swamps and succeeding ponds. It is postulated that *Cordaites* sp. B leaves represent the foliage of the large *Dadoxylon* sp. (*Eu-Cordaites*) trees that presumably inhabited channel margins and perhaps elevated slopes. Given the exorbitant height of some of the interpreted parent trees, it is not difficult to envision some of the leaves being blown from the canopy into the stream, where by virtue of their coriaceous and robust construction (Mapes and Gastaldo 1986), they were able to survive fluvial transport and deposition on point bars. As well, some leaves may have been stripped by water currents from trees that collapsed into the river. Leaves within the floodplain sublithofacies at locality BB-25 probably were also wind transported, with aerial organ loss associated with either physiological or traumatic processes. The hypothesis that *Cordaites* sp. B leaves were derived from *Dadoxylon* sp. (*Eu-Cordaites*) trees fringing the channel is greatly strengthened by the complete absence of the foliage in the more distal clastic swamp sublithofacies at all localities.

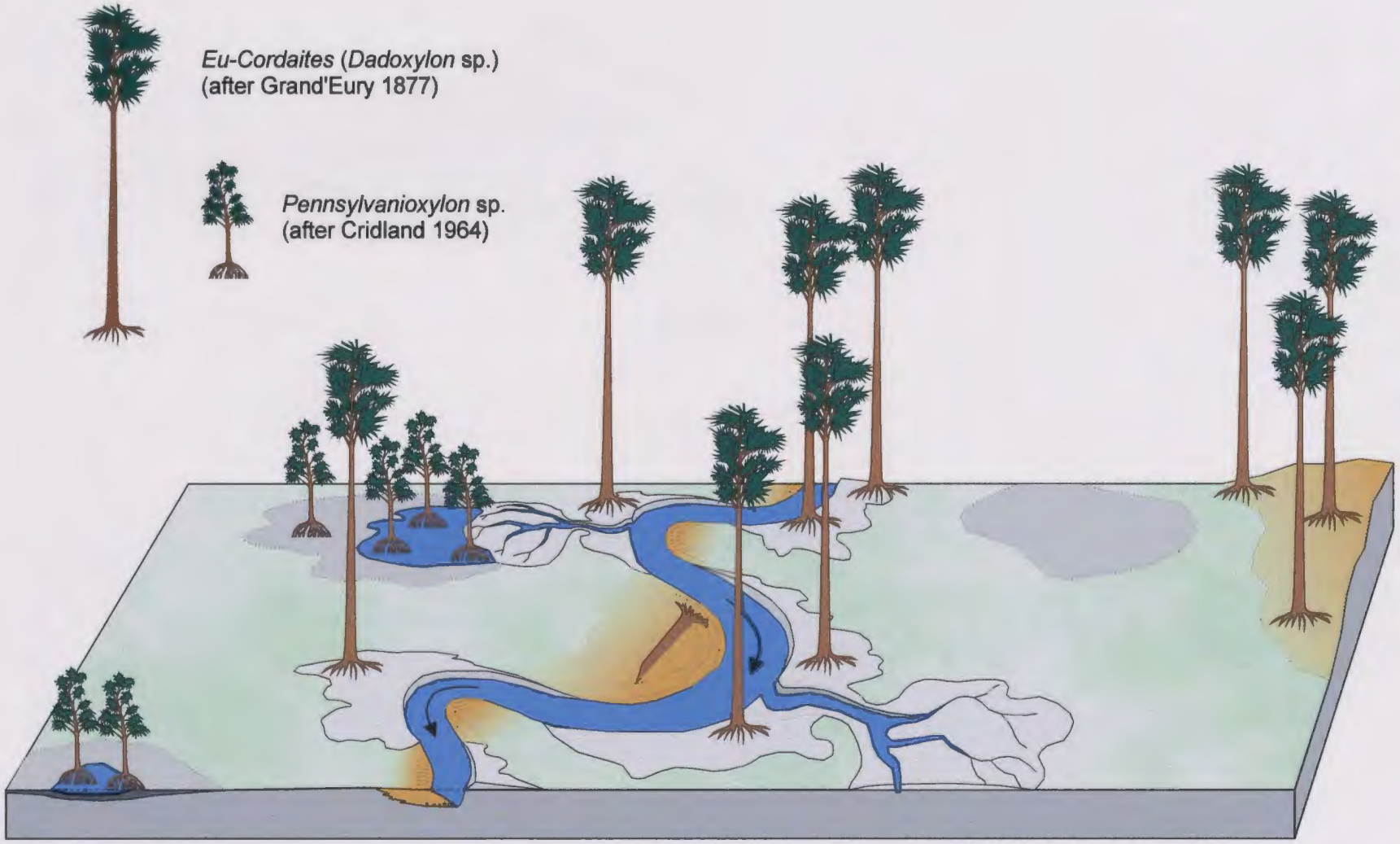


Figure 7.7. Hypothetical paleoenvironmental reconstruction with interpreted habitat preferences of cordaiteans recovered from Blanche Brook superimposed on meandering stream depositional environment. See Figure 6.18 for labelled distribution of sublithofacies.

As mentioned earlier, Schabilion and Reihman (1985) suggested that xeromorphic characters preserved in anatomically preserved cordaitean leaves represent adaptation of the foliage to growing under intense sunlight (i.e., "sun leaves"). This is consistent with the assumption that *Dadoxylon* sp. (*Eu-Cordaites*) trees growing along channel margins at Blanche Brook were very tall, canopy-forming trees exposed to considerable light. As well though, xeromorphic adaptations may also have reflected differential exposure to drying winds, or growth of the trees on comparatively dry substrates.

7.3 A Paleoenvironmental Model for the Blanche Brook Assemblage

Construction of a paleoenvironmental model for the fossil locality involves integration of interpreted habitat preferences of taxa within the Blanche Brook Assemblage with various sublithofacies that composed the depositional environment. It is imperative to state that this "working" model represents only one interpretation, and is subject to change with additional data. The following is a summary of the paleoenvironmental model illustrated in Figure 7.8.

Shifting substrates of the rather inhospitable point bars likely were devoid of plants except rhizomatous calamiteans, some of which presumably bore cf. *Asterophyllites* sp. foliage. In comparison, very diverse plant assemblages probably inhabited channel-flanking levee/backlevee complexes that evidently were of low elevation and consequently were frequently breached or overtopped by flood waters. The riparian flora interpreted to grow on this slightly elevated but comparatively well drained habitat apparently was dominated by very tall, woody, canopy-forming trees of cordaitean affinity (*Dadoxylon* sp. or *Eu-Cordaites*). These long lived trees likely

Figure 7.8. Composite hypothetical paleoenvironmental reconstruction incorporating interpreted habitat preferences of five major Late Carboniferous plant groups represented at Blanche Brook (Figs. 7.3 to 7.7) superimposed on meandering stream depositional environment. Refer to Figs. 7.3 to 7.7 for key to plant identifications. See Figure 6.18 for labelled distribution of sublithofacies.

towered above and shaded a subcanopy consisting of medullosan pteridosperms (bearing *Neuropteris semireticulata* and possibly cf. *Laveineopteris tenuifolia* foliage), *Sutcliffia* sp. (producing paripinnate and caducous fronds of *Linopteris neuropteroides*), some marattialean and filicalean tree fern species, and possibly calamitean subtrees. Ground cover might have consisted of dense, branching thickets of sphenophylls, such as *Sphenophyllum emarginatum* and *S.* sp. cf. *S. zwickaviense*. Comparatively more elevated and consequently drier levee/backlevees probably supported stands of arborescent sigillarians.

Predominantly grey, thoroughly phytoturbated and rooted floodplain deposits within the succession indicate that alluvial paleosols formed at or very near the water table and must have supported profuse stands of vegetation. It is postulated that medullosan pteridosperms, calamitean subtrees (bearing *Annularia sphenophylloides*, *A. stellata* and *Asterophyllites equisetiformis* foliage) and tree ferns(?) formed a dense subcanopy on the floodplain, while *Lepidodendron hickii* and possibly "*Lepidodendron*" sp. cf. "*L.*" *bretonense* might have formed a tall but non-shading canopy; sphenophylls might have formed a dense ground cover. There is some evidence for strong interspecific ecological habitat partitioning within the medullosan pteridosperms occupying the floodplains. In particular, it is possible that trees bearing *Laveineopteris rarinervis* foliage grew on comparatively wet, topographic lows peripheral to clastic swamps and in distal portions of floodplains, while cf. *Laveineopteris tenuifolia* occupied substrates with drier edaphic conditions on proximal floodplains and some levees. Meanwhile, trees bearing *N. semireticulata* foliage, along with rare *Macroneuropteris scheuchzeri-*

producing trees, might also have preferred slightly more elevated and better drained substrates more proximal to the active channels. This slightly dryer ecological niche on well developed floodplains and levees likely was also occupied by arborescent sigillarians, although evidence suggests that these lycopsids grew only at localities where medullosan pteridosperms were uncommon or even absent.

Clastic swamps evidently were heavily vegetated by a diversity of plant groups, although temporal and spatial ecological gradients likely existed depending on whether peat accumulation exceeded clastic input, or vice versa. Data from miospore assemblages indicate that a considerable number of lycopsids grew within most of the clastic swamps, although they may have been absent from some swamps. It is postulated that arborescent trees, such as *Lepidodendron hickii*, coexisted with *Sigillaria* sp. and marattialean and filicalean tree ferns (bearing pecopterid and lobatopterid foliage) when substantial clastic influx from frequent flood incursions resulted in relatively drier (but still wet), exposed clastic substrates. Conversely, it is inferred that arborescent forms such as "*Lepidodendron*" sp. cf. "*L.*" *bretonense* (=*Diaphorodendron scleroticum*) inhabited the wetter, more submerged, peat substrate intervals of swamp development. The lycopsids *Chaloneria* sp. and *Sellaginellites* sp. may have formed an understory during these wet phases, or may have occupied more open areas of the swamp.

Evidence suggests that cordaitean plants, probably mangrove- or shrub-like *Pennsylvanioxylon* spp(?) trees bearing *Cordaites principalis*-type foliage, comprised much of the biomass within, and likely directly peripheral to, the clastic swamps. These cordaiteans, along with some marattialean tree ferns, ficialean ferns and calamiteans,

presumably formed part of the subcanopy beneath taller arborescent lycopsids. Like in other habitats, swamp-dwelling sphenophylls might have formed a dense undergrowth beneath the subcanopy.

Although it is not possible to ascertain the vegetation (if any) of comparatively dry extrabasinal lowlands surrounding the lowland-wetlands, it is inferred by analogy that these somewhat elevated, well drained substrates might have been occupied by large, woody, forest-forming trees represented by *Dadoxylon* sp. petrifactions (*Eu-Cordaites* trees).

Chapter 8 – Conclusions

- The Blanche Brook Assemblage, which includes an array of macroflora representing each of the major Late Carboniferous plant groups (lycopsids, sphenopsids, ferns, pteridosperms and cordaiteans), flourished on the southern margin of paleoequatorial Laurentia as part of the Europe Paleoarea of the Euramerian Paleokingdom. More precisely, the assemblage forms part of the Acadian Floral Province, which was separated from the Interior-Appalachian Floral Province of midcontinental North America by the northern Appalachian Mountains.
- Foliage is predominantly preserved as devolatilized adpressions, although "naturally macerated" volatilized adpressions of certain taxa were recovered. Enormous and often uncompressed trees of cordaitean affinity are preserved as volatilized petrifactions.
- Paleoecological evidence and homotaxial biostratigraphic correlation of selected taxa with macroflora from other localities in the Maritimes Basin of eastern Canada, western and central Europe, and midcontinental North America establishes that the Blanche Brook Assemblage is Middle to Late Bolsovian in age, which confirms previous age determinations based on miospore assemblages.
- Recovery of cuticles with very well preserved epidermal details from foliage of *Cordaites* spp. and several medullosan pteridosperms indicates that at least 28% of volatile components remain within adpressions. This corroborates earlier conclusions that rocks in the northern part of Bay St. George Basin and on Port au Port Peninsula

are thermally immature, and verifies that further cuticular investigations of macroflora from Blanche Brook are warranted.

- Fossiliferous strata accumulated in a coarse grained, mixed-load meandering stream system that flowed southwestward down the axis of a narrow alluvial plain occupying a small subbasin in the northern extreme of the Bay St. George Basin. Channel flow was poorly confined by topographically low levee/backlevee complexes that were consequently overtopped or breached during frequent flood events. Overbank sediments are characterized by grey floodplain paleosols and coal-bearing clastic swamp deposits, which attest to accumulation under waterlogged, reducing conditions. However, the presence of some reddish channel and floodplain strata indicates occasional deposition under well drained conditions, and suggests fluctuations in the water table or rate of basin subsidence.
- Integration of interpreted habitat preferences of taxa with the meandering stream depositional environment has resulted in a reconstructed working paleoenvironmental model for the Blanche Brook Assemblage. Riparian floras included calamiteans on some point bars, whereas levee/backlevee complexes were inhabited by a towering canopy of *Eu-Cordaites* trees that shaded a subcanopy of medullosan pteridosperms (*N. semireticulata*), *Sutcliffia* sp. (*L. neuropteroides*), filicalean and marattialean tree ferns, and possibly calamitean subtrees; sphenophylls (*S. emarginatum* and *S.* sp. cf. *S. zwickaviense*) may have formed dense thickets of ground cover. Higher and better drained levee/backlevees evidently supported stands of arborescent sigillarian lycopsids. The subcanopy on floodplains likely comprised calamiteans (*A.*

sphenophylloides, *A. stellata*, *A. equisetiformis*), medullosan pteridosperms and perhaps some tree ferns, with a tall but non-shading canopy of *Lepidodendron hickii* and possibly "*Lepidodendron*" sp. cf. "*L.*" *bretonense* (=*Diaphorodendron scleroticum*); sphenophylls may have provided ground cover. Evidence of interspecific habitat partitioning within the pteridosperms suggests that *N. semireticulata* and cf. *L. tenuifolia* occupied drier, more proximal floodplains and levees, while *L. rarinervis* may have inhabited wetter, more distal floodplains peripheral to clastic swamps. Competition may have existed between *N. semireticulata* and arborescent sigillarians for occupation of the better drained proximal floodplains and levees. Clastic swamps were inhabited by a diverse flora, the composition of which depended on the rate of peat versus clastic sediment accumulation. *L. hickii* and sigillarian lycopsids likely coexisted on the drier, clastic substrates, whereas "*L.*" sp. cf. "*L.*" *bretonense* and the smaller forms *Chaloneria* sp. and *Sellaginellites* sp. inhabited the wetter, partially submerged peat substrates. Other significant subcanopy flora in the clastic swamps included mangrove- or shrub-like *Pennsylvanioxylon* spp(?), marattialean tree ferns (*Lobatopteris* spp. and *Pecopteris* spp.), filicalean ferns and some sphenopsids. Similarly to the well drained levee/backlevees, extrabasinal lowlands may have supported stands of tall, forest-forming *Dadoxylon* sp. (*Eu-Cordaites*) trees.

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Appendix 1 - Procedure for Cuticle Preparation

The procedure described here is only one of several methods used in cuticle preparation from phytolemmas; more extensive reviews of these techniques are given by Barthel (1961, 1962) and Kerp (1990).

- Place small fossiliferous slab in shallow **plastic** bowl or tray and add 48 to 50 % hydrofluoric acid (HF) just until specimen covered.

> ♦ Extreme caution should be exercised when using HF, as it is frighteningly caustic. Always wear rubber gloves, apron and goggles, and work under a fume hood using plastic equipment.

- Let sample stand until entire phytoleim dislodged; occasional gentle agitation of HF helps to isolate the adpression from matrix.
- Remove adpression to slightly acidified (i.e. containing a few drops of HF) distilled water and discard partially digested slab to proper acid disposal bin.

> Mix concentrated Schulze's Reagent, an oxidizing solution that macerates and softens coalified matter from the phytoleim, under fume hood:
>
> - Combine approximately two scoops potassium chlorate to 150 mL 70% nitric acid.
> - ♦ *Schulze's Reagent should not exposed to skin and fumes should not be breathed in.*

- Remove all of slightly acidified water from sample before adding ca. 10 to 20 mL of Schulze's Reagent to petri dish under a fume hood. Maceration times are variable and depend on taphonomy and taxon prepared, but the maceration process should generally result in a light to rusty brown cuticle after approximately 1 to 2 hours.

- Once cuticles properly macerated, add drops of less concentrated Schulze's Reagent to the sample, then eventually drops of distilled water in order to rinse specimen of oxidizing agent. (This should be done slowly because violent reactions occur between the reagent and water, resulting in destruction of cuticles).

Mix alkaline solution, a basic aqueous solution that removes remaining softened coalified matter and rinses specimen of any oxidizing solution:

- Combine ca. 15-16 mL 28% ammonium hydroxide into 300 mL distilled water

- Decant most of water from petri dish before adding drops of alkaline solution. Gently agitate cuticles and dark brown plumes should form around specimens as they are rinsed of softened coalified matter. Cuticles may automatically partly separate into an upper and lower cuticle during this process. (Alkaline solution should be added only a drop at a time because violent reactions occur between the solution and coalified matter, resulting in destruction of cuticles).
- Rinse specimen with water until free of alkaline solution.
- In water filled petri dish, tease apart abaxial (lower) and adaxial (upper) cuticles using needles or dental tools with very fine points.
- Using pipette, remove cuticle(s) from water and place on slide. Attempt to orient specimen flat, then slowly evaporate water from slide by placing in intervals on hot plate (without burning cuticle).

Prepare glycerin jelly for slide mount:

- Add tiny pinch of Safranin O dye to given amount of heated (i.e. less viscous) glycerin jelly and stir until completely dissolved.
- Let stand for ca. 1 week in test tube in water filled beaker on hot plate to slowly remove any bubbles.

- Add tiny drop of stained glycerin jelly to slide and slowly lower cover slip onto slide.

Appendix 2 - Procedure for Staining for Carbonate Composition

This procedure represents a summary of the technique devised by Dickson (1965, 1966) for staining of a carbonate sample to determine which minerals are present – calcite has a variable stain color from very pale pink to red; dolomite will not be stained.

Mix etching solution under fume hood:

- Combine 15 mL 36% hydrochloric acid (HCl) into 500 mL distilled water before topping up solution to 1000 ml with distilled water.
- *HCl should not exposed to skin and fumes should not be breathed in.*

Mix three (A, B & C) staining solutions:

- Solution A – Dissolve 0.2 g Alizarin red S powder in 100 mL 1.5% HCl solution (12.5 mL 36% HCl in 237.5 mL distilled water)
- Solution B – Dissolve 2.0 g Potassium Ferricyanide crystals in 100 mL 1.5% HCl solution. (Note that solution B must be prepared fresh for each staining session.)
- Solution C – Combine 3 parts Solution A with 2 parts Solution B. (Note this combined staining solution lasts only for one staining session.)

- Immerse uncovered thin section in etching solution for 10 to 15 seconds at ca. 20°C before bathing the thin section in dish of warm water to avoid inhaling dangerous fumes.
- Immerse thin section in warm (combined) staining solution for 30 to 45 seconds.
- Gently wash thin section in bath of distilled water for a few seconds before removing and quickly drying slide surface under stream of warm air (e.g. hair dryer).

Appendix 3 – Sample Preparation for X-ray Diffraction (XRD)

Prior to analysis of a single tree petrifaction sample (23-2), the specimen was prepared for XRD by the following method:

- Extract tiny sample (< 0.5 g) from specimen with stainless steel blade and add to agate mortar.
- Add small amount of methanol to mortar and crush sample into very fine slurry with agate pestle.
- Remove part of slurry with pipette and mount very thin blanket (ca. 4 cm^2) of mixture on clean, dry, glass slide. After methanol rapidly evaporates, specimen is ready for analysis.